5.4 BONDING & INSPECTION

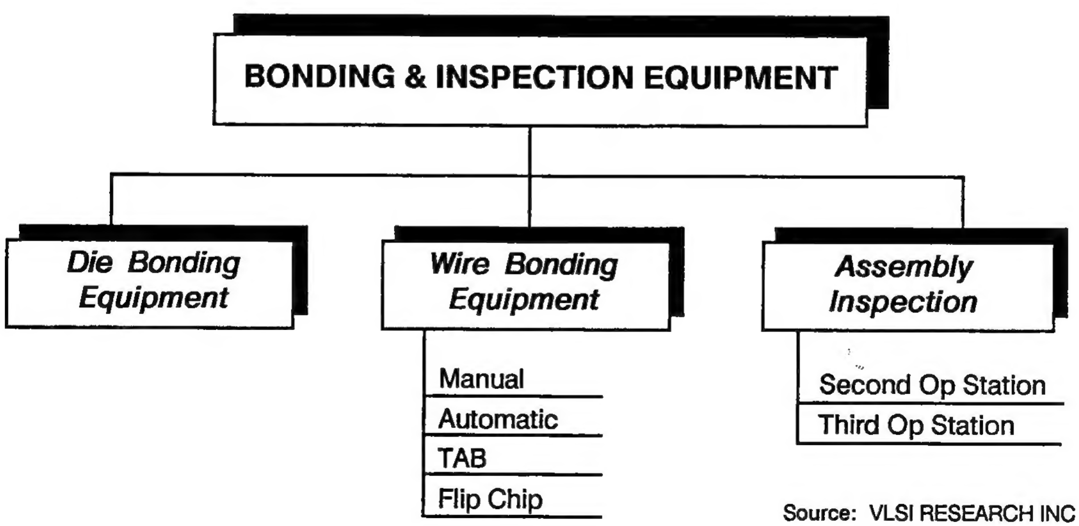
5.4. BONDING AND INSPECTION

- **Technological advances in the front end are bringing about dynamic changes in the back end.**
- **Increasing die size, lead count, speed and finer pitches are out dating current bonding equipment.**
- **Die and wire bonding sales have more than doubled in the past ten years.**

Bonding and inspection has historically been overlooked by upper management in semiconductor companies. Their attention has been drawn by the enormous capital requirements of wafer fabrication. However, this has been changing as the enormous advances in the front end have driven dramatic need for change in bonding and inspection equipment. The forces driving these changes are increasing die size, lead counts, device speed and finer pad pitches. **With die becoming larger and lead counts increasing, the installed base of bonding equipment is becoming obsolete.** The performance of assembly equipment is now critical to all semiconductor companies who want to produce value added products. The how's and why's will be discussed in greater detail in Section 5.4.1.2 'Technology'.

Bonding and inspection equipment consists of die bonding equipment, wire bonding equipment and assembly inspection equipment (see Presentation 5.4.0-1).

Presentation 5.4.0-1



Source: VLSI RESEARCH INC
2254-1P

There are two steps in the bonding process, die and wire bonding. These procedures involve attaching die to lead frames and coupling wires between the die and frame for electrical connections. Inspection takes place during die and wire bonding. Inspection equipment inspects die before they are bonded to lead frames and after they are wire bonded, scrutinizing both die as well as bonds to ensure proper bonding.

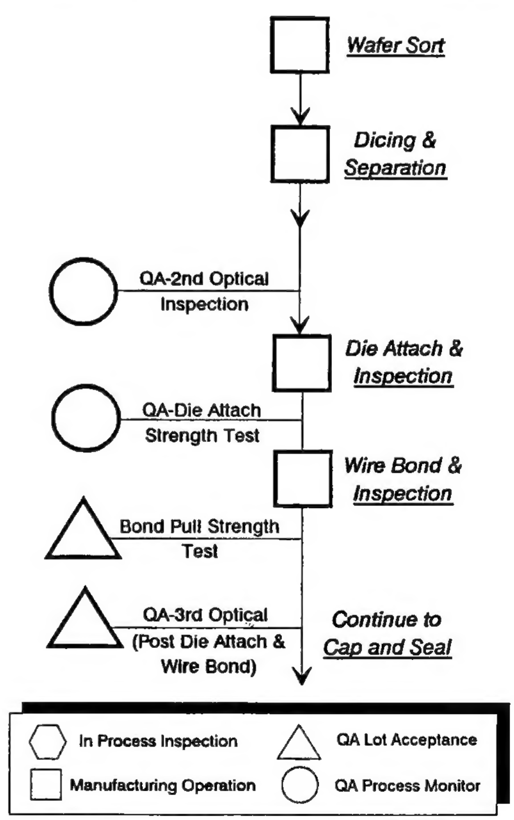
Die bonding equipment is an essential component of the assembly process. It is done directly after dicing, and just prior to wire bonding. The purpose of this equipment is to detach the die from the wafer and bond it to a lead frame. First the die is picked from either a diced wafer, storage station or waffle pack, then it is aligned to a target pad on a carrier or substrate. It is then permanently attached to the substrate by either a eutectic or epoxy bond. When cerdip packages are used, the lead frame is an integral part of the package. But if a plastic dip is used, the lead frame provides a substrate for the die until it can be surrounded by plastic at the molding step and become a complete package.

Wire bonding is the heart of an assembly line. Wire bonding equipment connects the die bonding pads to the lead frames or substrate, via wires or solder bumps. Wire bonding equipment consists of manual wire bonders, automatic wire bonders, gang or tape automated bonders (TAB) and flip chip bonders. The diversity of equipment has arisen from a variety of production requirements. Of all wire bonding equipment, automatic wire bonders are by far the most popular. Such equipment must perform a number of jobs. For example, they must first find the correct bonding pad–an area typically less than 5 $mils^2$ in size. Then they must attach the wire to the pad. Next, the bonding head which holds the wire must string the wire out in fish-line fashion, loop it, and then attach it to the proper point on the lead frame, and finally, detach and mold the remaining wire back into a ball on the bonding head. Moreover, these movements must be repeated very rapidly. Typically, it is done in 150 milliseconds for each wire. The fastest wire bonders are approaching 100 milliseconds per wire. Loop height must also be controlled to dimensions of only a few mils.

Inspection equipment is no longer necessary to the bonding process. This is because it has become an integral part of modern bonding systems. Historically, the primary inspection systems used in assembly have been second optical stations and third optical stations. Second optical stations check the die for physical damage after dicing. Third optical stations checks for mechanical defects in the die and wire bond. Presentation 5.4.0-2 illustrates the bonding and inspection procedure.

Presentation 5.4.0-2

Assembly Front End Process Steps



Source: VLSI RESEARCH INC
2254-2D

During the eighties, die and wire bonding sales more than doubled, while assembly inspection sales barely increased by less than half in the same time period (see Presentation 5.4.0-3).

In the wire bonding market, automatic bonders and TAB make up the majority of the increase in sales. Both are expected to continue growing rapidly.

Presentation 5.4.0-3

Fifteen Year Look at the Bonding & Inspection Market

	1975	1980	1985	1990
Bonding & Inspection	18.1	136.5	260.9	315.4
Die	2.2	31.8	82.5	87.9
Wire	15.9	99.4	170.9	220.4
Manual	10.8	18.5	17.6	13.5
Automatic	4.1	76.7	146.2	179.3
TAB/gang	1.0	4.2	7.1	27.7
Assembly Inspection	–	5.3	7.5	7.0
Second Op			5.3	2.8
Third Op			2.2	4.2

Source: VLSI RESEARCH INC
2254-3P

5.4.1 CURRENT INDUSTRY CHARACTERISTICS

(Index continued on next page)

5.4.1 CURRENT INDUSTRY CHARACTERISTICS

5.4.1 CURRENT INDUSTRY CHARACTERISTICS

- **More precise bonding equipment is required because of finer pitch, increasing die size and increasing pin counts.**
- **Stricter control on wire length and loop height is required of today's wire bonders.**
- **High lead counts are the main driver of longer wire lengths. TSOPs are the main production driver of low loop heights.**

Bonding equipment is being driven by the continuing trend to pack more transistors on larger die, while placing them in smaller packages. Larger die, greater number of leads, and thinner, smaller packages represent opportunities for assembly equipment manufacturers.

For die bonders, increasing die sizes and finer pitch require more precise die bonding equipment. **Precision alignment and placement of die becomes especially critical when the pitch between leads become smaller and narrower.** Without accurate placement, alignment between leads and pads will be off. If leads are misaligned, bonding speed will be slowed, since the bonder will take longer to acquire the appropriate pattern. Additionally, yields will be lower due to wire sweep problems at molding. Thus, precisely defined alignment is essential.

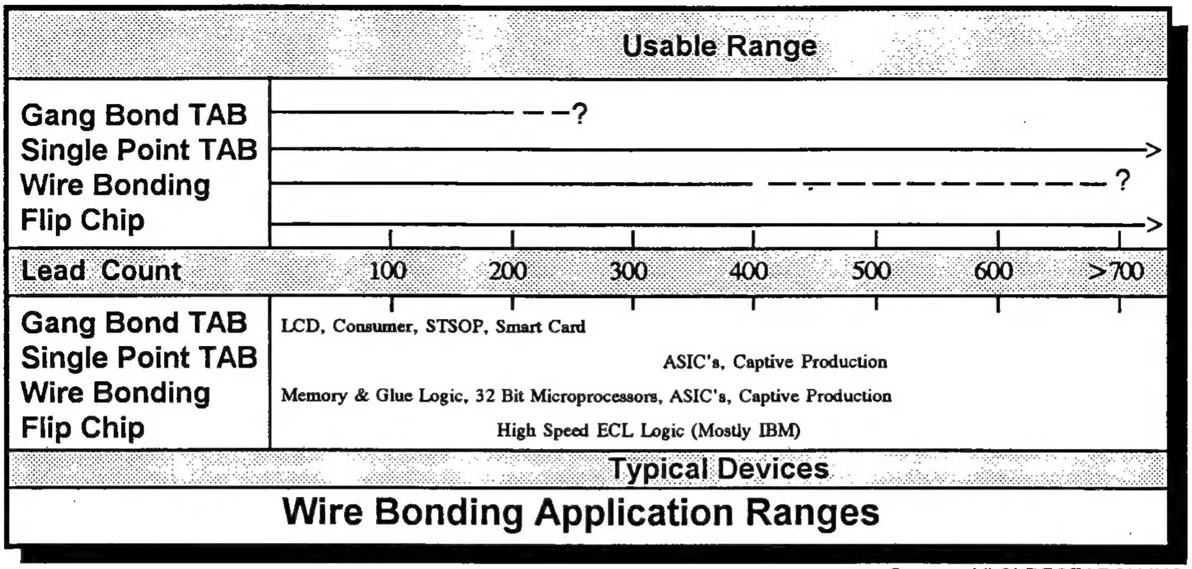
For wire bonders, larger chips with more leads require narrower pitches, and longer wire lengths. Thinner packages require lower loop heights. Today's wire bonders must possess greater control in order to achieve longer wire lengths and lower loop heights than ever before. If these variables are not controlled, there is a greater probability of adjacent wires being swept over during molding and shorted against each other or being close enough to cause cross-talk between wires.

Conventional wire bonders continue to have the widest range of use. They are capable of handling most of today's package styles and lead count ranges (see Presentation 5.4.1-1). They are also the most flexible bonder for production use. Gang bonded TAB is the most efficient of all bonders. Single point TAB offers high lead counts and flat wiring. **TAB also offers the flattest wiring possible. This makes it essential for Super Thin SOPs. Flip chip offers the highest lead counts possible.**

Smaller Packages Affects on Bonding

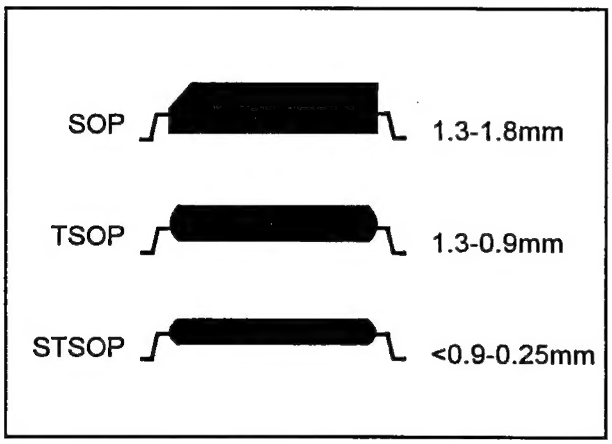
There are a number of new packaging technologies to meet the increasing demand for greater packing density. Two of these are thin small outline packages (TSOPs) and super thin small outline packages (STSOPs) (Presentation 5.4.1-2). TSOPs and STSOPs are also driving increased interest in flip chip and TAB.

TSOPs are becoming popular because they are roughly three times thinner and four times smaller than traditional small outline packages (SOPs). Manufacturers can attach



Source: VLSI RESEARCH INC
2254-42P

Presentation 5.4.1-1



Source: VLSI RESEARCH INC
2254-26D

Presentation 5.4.1-2

Examples of Packaging Miniaturization

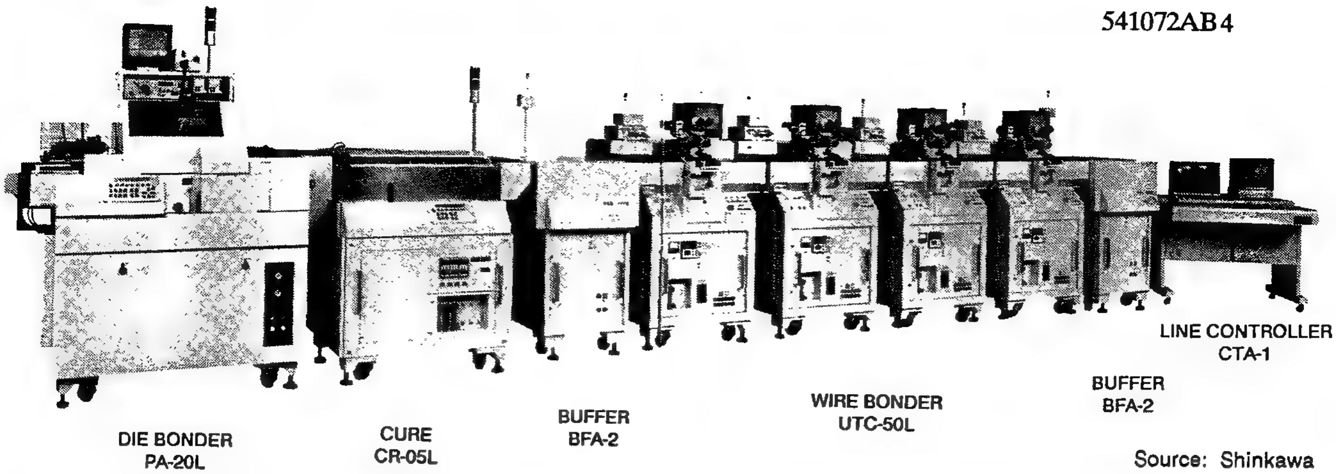
chips on both sides of the circuit board, creating a mirror-image quality with board thicknesses similar to that of a single-side board. This is especially important in portable applications such as notebook PCs and 2.5" disk drives.

5.4.1.1 Development of the Industry

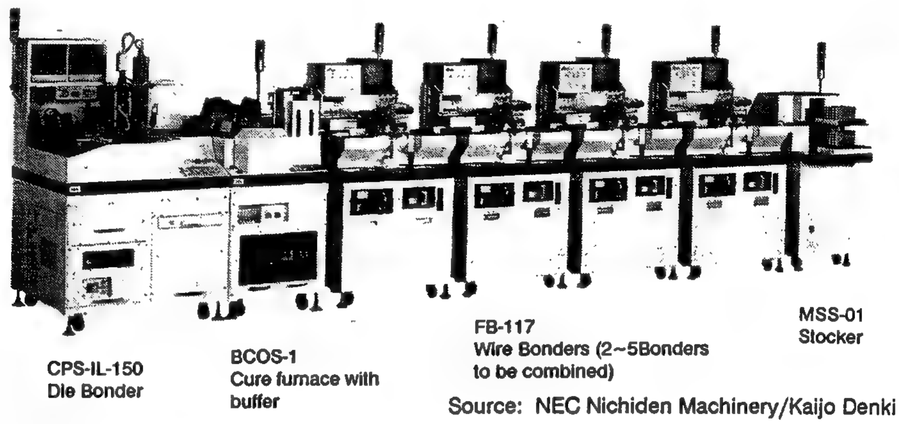
- **Die and wire bonding market has been one of the major areas of activity in equipment automation.**
- **Shinkawa is the first company to successfully manufacture an in-line assembly system.**
- **Inspection equipment is being incorporated into bonding equipment.**

Since its earliest days, the bonding market has been driven by the need to mechanize the assembly process. It was the earliest market to have activity in equipment automation. Availability of automatic systems has grown substantially in the past twenty years. In 1974, there were few available automated die and wire bonders, representing only 14% of all sales. By the eighties, they amounted to over 80% of all bonding equipment sales. In the nineties, automated equipment accounted for almost 90% of the bonding equipment market.

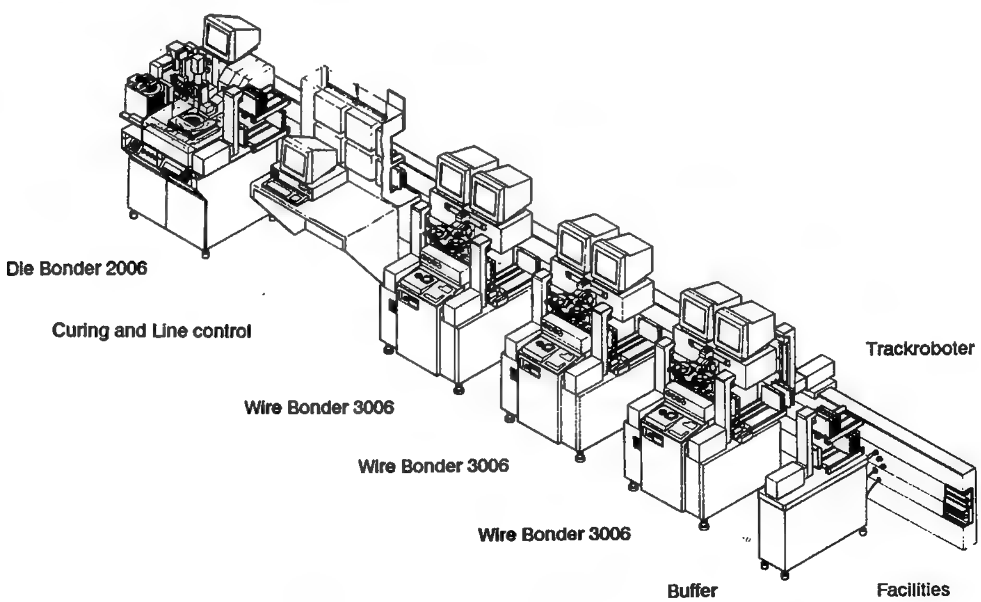
Eventually, this trend brought the development of assembly in-line systems. In the early eighties, Dias Automation came out with an in-line assembly system which connected die and wire bonders. Instead of being an asset, this system became Dias Automation's achilles heel. Reliability was the problem. By linking up the two bonders, reliability and uptime decreased, Dias Automation was never able to overcome this problem. Shortly after Dias' failure, Toshiba got everyone's attention with it's captively-made in-line assembly system. This system included equipment from die attaching to packaging the die. While reliable, this in-line system still had flexibility problems. Thus, it only sold well for DRAMs and other commodity applications. Shinkawa was the first company to successfully manufacture an assembly in-line system. In 1987, Shinkawa introduced its In-Line System SIL-1004 which automatically attaches die, cures and interconnects wires in an assembly line fashion. Presentation 5.4.1.1-1 illustrates this assembly line system and others. The line can be taken apart and assembled depending on production purposes. More importantly it could be programmed to handle a few different lead frame types. A wafer mounter, dicing saw and molder can also be integrated to this system. Later, other companies followed Shinkawa's lead. In the latter eighties NEC Nichiden Machinery and Kaijyo Denki, together, introduced an automated assembly line system. NEC Nichiden Machinery's die bonder and cure furnace and Kaijyo Denki's wire bonders and stocker systems were united in its In-Line System. With this system, individual lead frames are die bonded and then directly transferred to the first available wire bonder station. Kulicke and Soffa Industries inaugurated its Flex-Line Integrated Assembly System at SEMICON/West in 1991. This system is fully automated and consists of a single die bonder and several cure oven and wire bonder stations. ESEC has also developed a prototype multi-path assembly line system, called the ESEC AUTOLINE-In-line system. This system is



Source: Shinkawa



Source: NEC Nichiden Machinery/Kaijo Denki



Source: ESEC Autoline

2254-14

Presentation 5.4.1.1-1

Assembly In-Line Systems

configured as a magazine track line that feeds die bonders, cure ovens and wire bonders. ESEC presently sells a single path assembly line which consists of only the die and wire bonders. The primary advantage of the magazine track approach is that it is flexible, which takes full advantage of the inherent flexibility designed into ESEC's bonders.

Today's need for automation in assembly comes from the great variety of chips and packages in manufacturing. This variety continues to become more common as device manufacturers seek high value niches to avoid commodity markets. **There is a need to convert from one device to another without stopping the manufacturing process or diminishing its productivity.**

5.4.1.1.1 Development of the Die Bonding Equipment Industry

The die bonding equipment market is relatively new. It began to emerge in the late seventies with AMI's introduction of the first automatic epoxy die bonders in 1978.

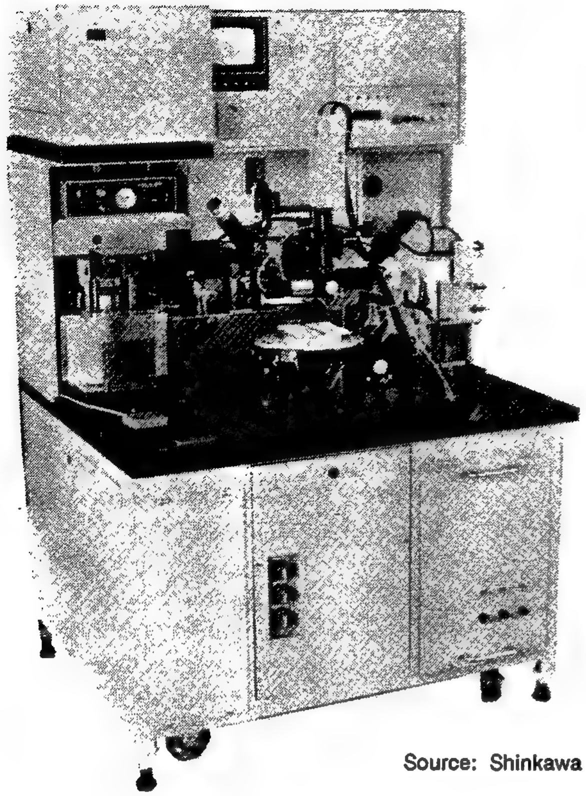
Prior to that time, die bonding was done manually. Using only tweezers, the operator placed a lead frame over a heating block, then placed a gold eutectic preform on the lead frame, and then, placed the die over the preform. The preform and die were heated to their eutectic bonding point while the die was scrubbed back and forth with tweezers onto the lead frame. It was tedious and slow. Eventually, tweezers were replaced by vacuum wands. However, these steps were not easily automated.

Automation of die bonding became viable with the advent of microprocessor controls for equipment and with the development of conductive epoxies. It was at that time that automatic die bonding equipment began to take-off. Older versions of automated die bonding equipment are shown in Presentation 5.4.1.1.1-1.

The mechanical make up of die bonders was largely dependent on the adhesives used to attach the die. Historically, a gold eutectic bond has been the most common method of attaching the die to the frame. Organic adhesives were considered special-purpose adhesives and were used specifically for hybrid ICs. They were preferred only when it was necessary to minimize long-term thermal drift. This is caused in hybrids because several die have to be heated up collectively while each is bonded separately.

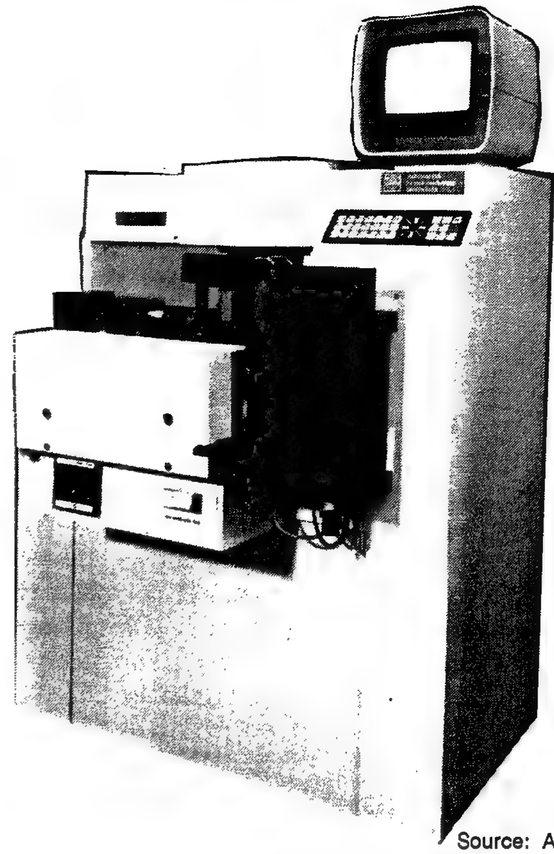
The use of gold eutectic bonds began to decline in 1973, when the price of gold was allowed to fluctuate at its free market value from its fixed price of $35 per ounce. Gold prices rose rapidly, reaching a peak of over $875/oz in 1979. At this high cost, the electronics industry was quickly spurred to search for less expensive alternatives. Consequently, the special-purpose organic adhesives were quickly adapted for commercial purposes. Epoxies were used first. Polyimides began to emerge in the late seventies.

Ever since the introduction of epoxies the advantages and disadvantages of epoxy versus eutectic die bond methods have been an issue. Epoxy has been a clear winner in terms of cost since the materials and equipment used are less expensive. Also, yields tend to be higher since the die is not heated during attachment. However, some technical considerations were a major barrier in using epoxy. Most NMOS and many bipolar digital devices require an ohmic connection between the die and the lead frame. Epoxy is not a good conductor of electricity. While special formulations of epoxies were developed, their resistance was usually too high. Moreover, epoxy tends to degrade at medium temperatures and outgas in a vaccum. Polyimides have similar problems.



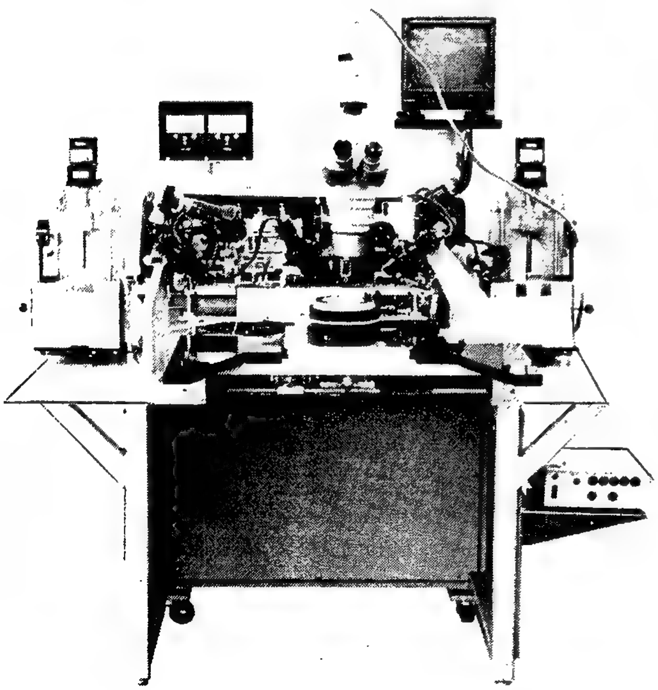
Source: Shinkawa

Model SPM-FA-PA-5H



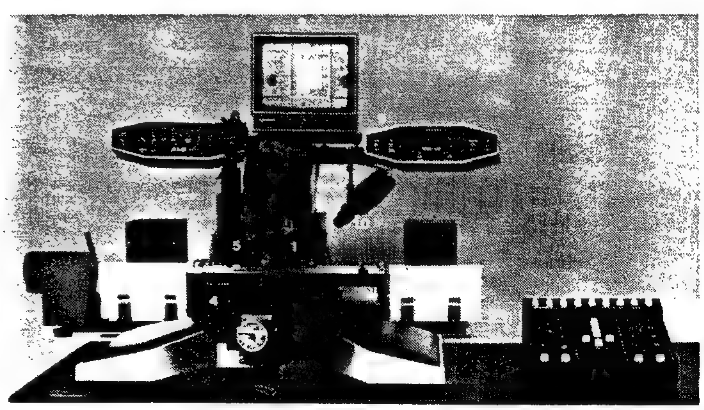
Source: ASM

Desert 2000



Source: Tokyo Sokuhan Co., LTD

Model DB-500EF



Source: AMI

Model 3100/3200

2254-10

Presentation 5.4.1.1.1-1

Older versions of automatic die bonders.

In addition, polyimides are more expensive than epoxies. However, they are preferred when low contamination and low void formation is desired.

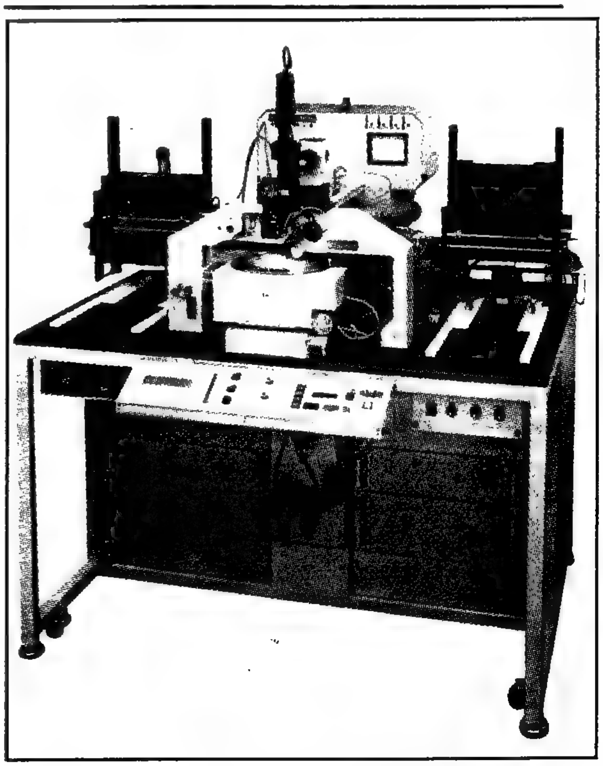
On the other hand the viability of eutectic bonds was well established. Eutectic attaching accomplishes what is essentially a metallic weld, so conductivity is equal to or better than all other methods. It is also void free, so it dissipates heat uniformly across the die. As much as 90% of all die bonds were still eutectic in 1979. Eutectic die bonding equipment continued to be purchased for applications where good frame-to-substrate conductivity was required. Such wide usage prompted the eventual development of automatic eutectic equipment. Yet, unlike epoxy adhesives, eutectic bonds are expensive. In addition, with eutectic bonding, the die is also heated, which causes a greater tendency of chip damage.

Thus, the development of new die bonding compounds continued. In the early eighties, Hitachi Chemical announced a liquid silver epoxy which eliminated most of the problems associated with epoxy compounds. In 1982, Johnson Matthey introduced a silver-filled glass. Silver glass adhesive requires high temperatures, solvents and binders for optimum adhesion. Generally, silver glass is used for large die, multichip and ceramic packages. Presentation 5.4.1.1.1-2 illustrates a semiautomatic die bonder for silver glass die attach.

Eventually, epoxy compounds came to dominate as most of the technical issues were resolved by the mid-eighties. Today, most automated die bonding equipment sold has a liquid dispense mechanism.

5.4.1.1.2 Development of the Wire Bonding Equipment Industry

The commercial bonder market began in the late 1950's. In 1956, the transistor won the Nobel prize in Physics. Western Electric approached the fledgling Kulicke & Soffa, a design and manufacturing firm, to produce a specialized piece of equipment to attach gold wires to and from the transistor. This equipment was to become the first commercial wire bonder. In fact, Kulicke & Soffa has the longest history of engaging in the equipment company and wire bonding is the oldest segment in the industry. Manual wire bonding became the workhorse of the industry for nearly two decades. The fifties was followed with a technically active decade in the sixties. During this time, manual gold wire bonders were extensively employed into production. Gang bonding also emerged. Flip chip, spider, beam lead and GE's mini-mod were all introduced in the sixties. These new methods were projected to take over the wire bonding market in the seventies. While they never did meet their promise, the following two decades would not match the technical creativity of the sixties. In the late seventies, mesa bond pad



Source: Alphasem AG
2254-11

Presentation 5.4.1.1.1-2

Automatic Silver Glass Die Bonder

was developed, and in the eighties bumped tape, copper wire and the micro bond pad were introduced (see Presentation 5.4.1.1.2-1).

Meanwhile, in the early 1970's, manual wire bonding began to be replaced by automatic wire bonding.

Presentation 5.4.1.1.2-1

ADVANCES IN BONDING TECHNOLOGY

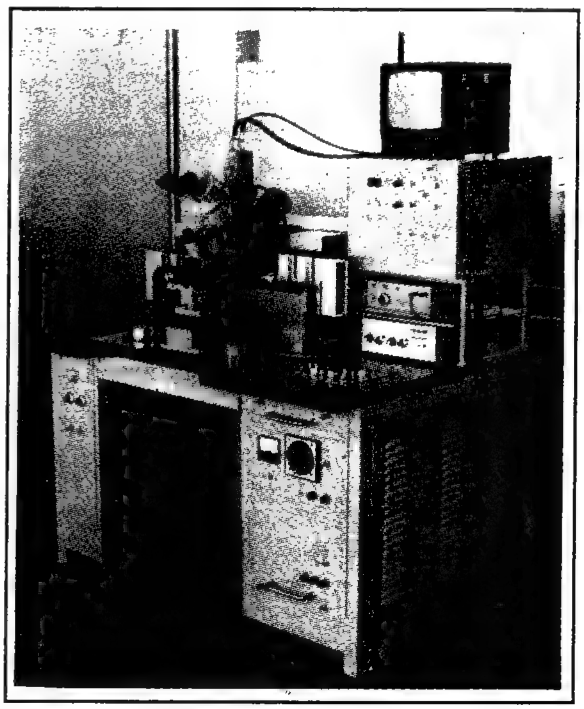
	1960		1970	1980	1990
Wire Bonding	*Manual Bonding*	*Au Wire* 1964	*Automatic Bonding* 1972 *Digital Bonding Head* 1977	*Single PointTAB* 1988 *Fine Pitch Pads* 1988 *Cu Wire* 1988	
Gang Bonding		*Flip Chip* 1964 *Minimod* 1968 *Beamlead* 1966 *Spider*	*Mesa Bond Pad* 1979	*Bumped Tape* 1981 *Micro Bond Pad* 1987	

Source: VLSI RESEARCH INC
2254-7P

1970's

In 1972, Shinkawa displaced Kulicke and Soffa's wire bond market share with the introduction of the first automatic wire bonder. This invention won Mikiya Yamazaki Shinkawa the Semi Award. Automatic wire bonders soon became the largest wire bonding segment, thus placing Shinkawa in the leading market position. An example of one of Shinkawa's early automatic wire bonders is illustrated in Presentation 5.4.1.1.2-2.

Several American companies soon followed the Japanese lead with automatic bonders. Even GCA entered the business briefly around 1976. In 1977, Kulicke & Soffa introduced a digitally-controlled bonding head. The bonding head on Shinkawa's early automatic wire bonders was analog controlled, which made it harder to program. The digital head represented a major technological advancement and an American reemergence as technological and market leaders in bonding. It allowed users the



Source: Semiconductor International, April, 1980
2254-15

Presentation 5.4.1.1.2-2

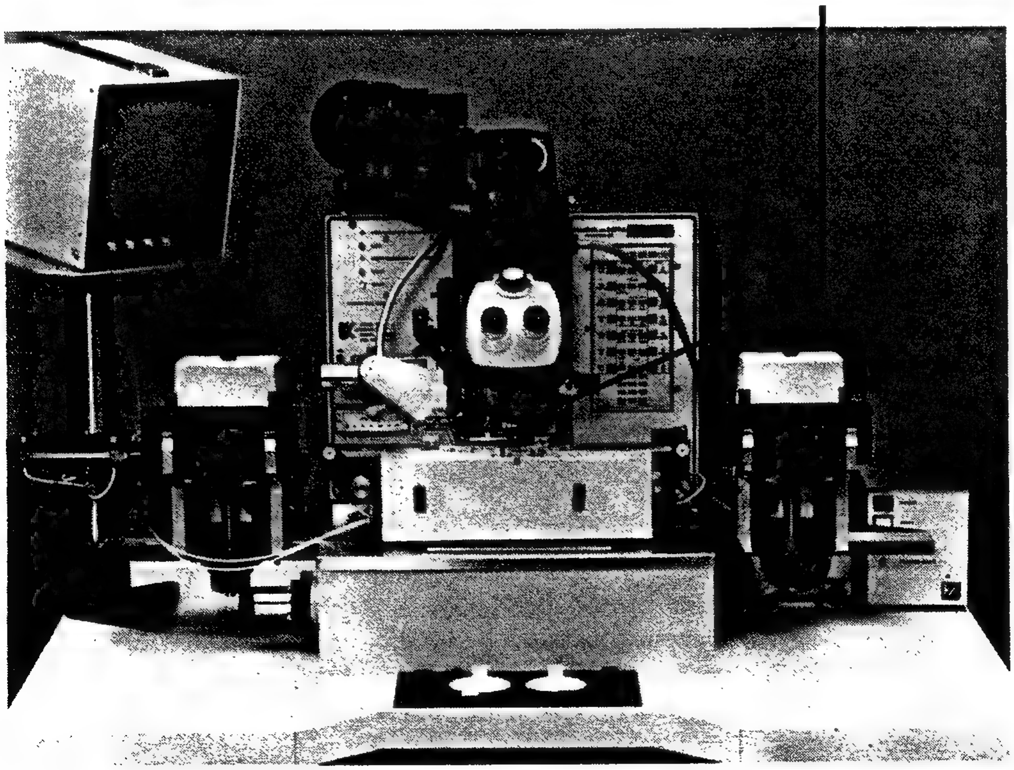
An early Shinkawa automatic wire bonder.

flexibility of changing semiconductor products and die type by making only a simple program change. It also provided them with flexible but low cost bonding on a large scale. In addition, assembly yields improved, since many potential operator errors were eliminated by using a computer controlled system. This placed America back in the forefront of bonding technology. Presentation 5.4.1.1.2-3 illustrates one of Kulicke and Soffa's early automatic wire bonders with a digitally-controlled bonding head.

In 1978, Jade introduced a machine with both automatic wire feed and correction which helped to substantially decrease wire breakage problems in automatic bonders. These features soon became standard on all machines. However, Jade was never able to break Shinkawa's and Kulicke & Soffa's hold on the market. By the mid-eighties, most bonding equipment suppliers offered similar features.

The steady improvement of automatic wire bonding also had a major impact on other wire bonding segments. As automatic bonders improved, requirements for gang or tape automated bonders (TAB) were further pushed into the future. Consequently, the market for gang bonders grew at a sub-

Digitally-Controlled Bonding Head: Microcomputer control eliminates mechanical cams and linkages; enables operator to vary bonding height, forces, and times, through direct keyboard entry of bonding parameters.



Source: Kulicke & Soffa
2254-16

Presentation 5.4.1.1.2-3

An Early Kulicke & Soffa Automatic Wire Bonder

stantially slower rate than the automatic wire bonding equipment. The market never became large enough to fund a level of R&D expenditures needed to allow TAB to advance over wire bonding.

In 1979, aluminum ball bonding emerged due to increases in the price of gold. In 1977, the cost of gold in the average IC package amounted to three or four times the cost of aluminum wire. By 1979, this ratio was approximately 17 to 1. The cost of using gold had more than doubled each year between 1977 and 1979. Manufacturers' profits were being reduced with each increase in the price of gold. In addition, the market for semiconductors had become highly competitive and the price of ICs became more critical to semiconductor users. It was therefore no surprise that semiconductor manufacturers were fervently attempting to eliminate gold from their process in late 1979.

1980's

Fortunately, the upward trend of gold prices ceased in mid 1980 and gold prices actually declined during the latter half of 1980. By the end of 1981, the price of gold had declined to about $500 below the peak value of $875/oz. Gold prices continued to decline over the next three years, and reached a low of $284/oz in early 1985. This price decline occurred because the demand for gold for manufacturing and jewelry would only support prices of around $300 an ounce. Price levels above this would be supported by speculative demand alone. Consequently, when prices exceeded $300/oz. there was a significant downward price pressure. So once the Iran hostage crisis was over and inflationary pressures had eased, gold prices became relatively constant. It has usually taken an international crisis to push gold price drastically above $400 an ounce.

Despite the price fluctuations of gold, aluminum ball bonding had not been very successful. Aluminum is much more difficult to control than gold. Aluminum wire tails from ultrasonic bonding is a problem as tighter packaging of bonding pads are required. In the late eighties, copper was experimented with to replace gold. Yet it was found that copper does not stick well to aluminum as both oxidize rapidly. Despite these efforts, gold ball bonding was and still is expected to remain the dominant technology for the foreseeable future.

Speed become a major concern in the early eighties. A balance had to be obtained between high throughput and wire bonding quality. Faster is better as long as yield does not suffer. High speed results from many bonding factors including such items as mechanical motion restriction on momentum transfer, vibration frequencies and wire handling. Kulicke & Soffa responded to these needs by introducing the first commercially available high speed automatic wire bonder, the 1482.

Two key factors arose in wire bonding as manufacturing split in two directions in the early eighties. The first was the homogenous commodity product line in which a large number of similar die were processed each week. The second was the low volume ASIC production line. Consequently, end users were buying a variety of wire bonders in the early to mid eighties, depending on their application and need. Manual wire bonding was largely replaced by automatic wire bonding for commodity production. As production runs of die with the same bonding pad pattern grew, switching to automatic bonders proved more economical.

However, automatic wire bonders were inflexible. Changing lead frames required changing workholders. This took thirty minutes at best and required costly inventories of spare workholders.

For niche applications, no substitute was found for a highly skilled operator with a manual machine. The trend in manual bonders moved toward more specialized equipment for devices such as microwave, power devices and certain hybrids. In addition, when many different types of die were being bonded in a given period, as had been the case in the past, manual bonding proved the most economical. For these reasons, and others, use of manual wire bonders continued .

Another motivation driving the trend to automatic wire bonding was wire bond consistency. Such consistency results in higher yields, more reliable circuits and increased throughput, which all help in controlling production cost.

By the late eighties, automatic wire bonders added the ability to self-inspect and correct for errors. Kulicke & Soffa continued to lead the technical forefront with wire bonders that out yielded its competitors. Flexible pattern recognition systems for component position referencing became reliable.

1990's

The next major advancement came from Switzerland. ESEC introduced a bonder that had full software control over the workholder. Its software system offered considerable flexibility for a wide range of customer needs and applications. It dealt with variable chip heights, wire lengths and loop shapes. It could changed lead frames, bond times, force needed from device to device via software. In addition, computer software control allowed networking a number of bonders via a single computer system. This allowed one operator, control of an entire production line. It also eliminated most of the mechanisms in the workholder, replacing them with software feedback control. This significantly increased the life of workholders.

Several issues began affecting wire bonding equipment and started to create many changes in the performance expectations of the equipment. The trend to larger die, finer pitch, higher lead count, lower loop height, and longer wire length became important drivers. Larger die, higher lead counts and thinner packages were rapidly obsoleting most equipment in the field. Lead counts above 130 pads obsoleted most wire bonders that were built prior to 1989; those above 200 leads obsolete all but one or two systems. The issues centered on controlling die size and wire length.

Kulicke and Soffa addressed these issues with its model 1484XQ ball bonder. Kulicke & Soffa and ESEC were noticeably addressing the wire bonding issues of the eighties. Shinkawa was conspicuously absent and trailed in wire bonding technology at this time. It was putting most of its efforts into developing TAB bonding for multichip modules.

Present day automatic wire bonders must be flexible enough to meet the constant changes in IC and package designs. Previously, the main emphasis was speed. Now, with the rapid widespread use of these more complex devices automatic bonders have to be more flexible.

Newer generation wire bonders reduce die size, so they actually pay for themselves by increasing the number of good die yielded from a wafer. They also add new capability for making the latest thin-SO packages. TSOPs demand far greater control of loop height than is available in older generation bonders. An additional driver of assembly is that higher lead counts translate into increasing die values which drive demand for bonders with dynamic process control. Newer generation bonders sense when they are trending out of spec and dynamically adjust, or shut down before they actually damage die.

Gang Bonding/Tape Automated Bonding

The first efforts to perform gang bonding can be traced back to IBM and General Electric (G.E.). In the mid-sixties, IBM developed solder bump technology. The solder bump process uses molten solder to attach directly to leads. The primary advantage of solder bumps, is that designers are not confined to the outer perimeters of a chip. Thus, lead counts are virtually unlimited. However, IBM's patents on this technology and its cost have generally limited its applications.

In 1968, Triggs and Byrns developed a film carrier technique at General Electric. It was patented in August, 1971. The patent covered the essential functions of tape automated bonding.

In the patent, they identified three primary regions around which bonding was to take place, bottom, top and middle regions. The 'bottom region' was a metallic layer of adhesive. The 'top region' was a bondable metallic layer with raised contacts. The 'middle region' was a metallic barrier layer used to join the top and bottom regions. This technique completely eliminates the die attach step. G.E. developed its 'minimod' bonding equipment using this method. Texas Instruments acquired the original 'minimod' TAB equipment form G.E. It produced this equipment for internal consumption only. Both Fairchild and Motorola developed similar gang bonding equipment. These were called 'Fairpak' and 'spider bonding', respectively. These developments assisted TAB in entering the forefront of bonding technology by the mid-seventies. Jade and Kulicke & Soffa offered some of the first commercially available TAB equipment at about this time as well.

Gang bonding promised substantial cost savings for large-scale semiconductor production. However, it never delivered. Most merchant semiconductor firms use automatic wire bonders rather than gang bonders.

This has been mostly due to the flexibility required by the typical merchant semiconductor firm. The typical lot size for a given product is about 50 wafers. For the average integrated circuit, this works out to be about 20K good die per lot that will need to be packaged. So about 25 program changes will be required each week for a typical assembly line of 500K die starts per week. Among smaller firms, programs are changed even more frequently, i.e. about 75 times per week. This can reach upwards of a 1,000 changes per week for some companies. TAB bonders do not have the flexibility to be used in this type of environment. TAB is not programmable since tapes must be changed each time the product changes. Consequently, much of the productivity gains associated with TAB are lost on small lots. Also, tapes must be individually tooled for each product, and inventories must be kept of each tape type. Typically, a line will process fifty different products. For small-scale lines, 120 different products are typical. The tooling and inventory costs can become quite large for the merchant manufacturer. For these reasons, TAB is rarely used for merchant semiconductor manufacturing.

Another area of development was with high lead count devices. TAB was initially limited to low pin-count devices—typically those below twenty pins. Breakage occurred in die with higher pin counts. This was due to the higher pressures required. Die yields were also a problem for TAB bonders. The pressure needed to bond each pad is fixed. If TAB is used with high lead-count devices, too much pressure is applied, leading to passivation cracking, or even die cracking.

The next major breakthrough in TAB was to come from Japan. In 1976, Sharp announced that it had succeeded in applying TAB to LSI devices (see Presentation 5.4.1.-

1.2-4). Sharp used a solder reflow technique that allowed bonding of up to 40 leads and alleviated the cracking problem. This represented not only a major advance in bonding, but also placed the Japanese in the position of being the technological leaders in TAB. In the late seventies/early eighties, TAB users were mostly concentrated in Japan and Europe. Companies such as NEC, Sharp, Casio, Seiko and Honeywell Bull in France. Many of these companies designed their own bonding equipment to gang bond moderate lead counts, TAB bonded devices. So, bonding equipment suppliers were virtually locked out of these captive companies.

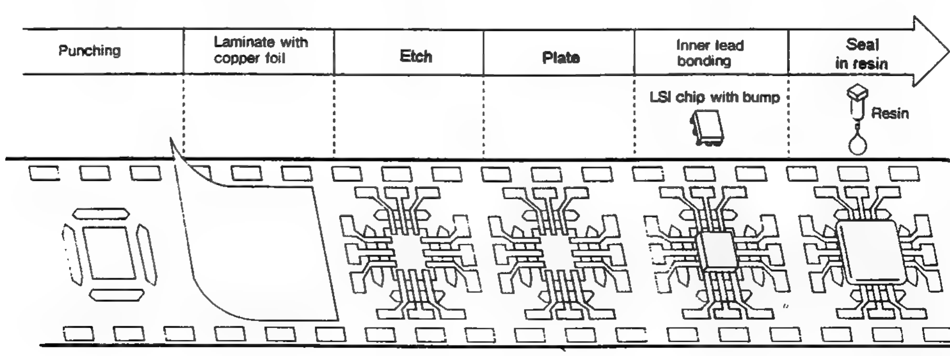
By the mid-eighties, gang bonding techniques were widely used for multichip modules in mainframe computers and in consumer electronics. At this time, high pin count chip requirements started compose a largest segment of gang bonding equipment demand. The reason was quite simple. Bonding pads were generally confined to non-active areas on the outer perimeter of the die. When pads became smaller than four mils on a side, wires could be dislodged from the pad by the capillary. Or the heels of the bond could touch and the device would short out. Thus, a device with 100 pads translates into a minimum die size of about 175 mils square (assuming 3 mils between pads). Consequently, TAB became very popular among captives and VHSIC sponsors. TAB was and is applied extensively in military uses and hybrid or MCM for consumer products.

This problem lead to the development of single point TAB bonding equipment. A single point TAB bonder is a conventional wire bonder without the wire. It utilizes TAB tape, a TAB tape work-holder, and a die presentation mechanism. This system solves the die yield problem since only one pad is bonded at a time. It is a lower volume production tool, and more flexible.

Nevertheless, merchant suppliers with large lines are finding uses for gang bonders. Smart card, watches, compact televisions, headphones, hearing aides, are good examples of consumer products driving the demand for TAB.

5.4.1.1.3 Development of the Optical Inspection Industry

Inspection of devices during assembly is not new. It has been an integral part of assembly since the industry's inception. In the 60's and 70's, most inspection had been



Presentation 5.4.1.1.2-4

Source: Nikkei Electronics
2254-44

Assembly of TAB LSI

done visually. No inspection equipment had been specifically designed for assembly until the latter half of the seventies when the use of microscopes in this industry began.

The development of assembly inspection equipment was spurred by the advent of automated bonding equipment. This equipment was so efficient and fast that it caused huge bottlenecks at inspection. Manufacturers soon found they needed rooms full of inspection stations just to keep up with the output of a few pieces of bonding equipment. Inspection equipment became critical because it was important to make sure that bad die was not being bonded.

Initially, assembly inspection equipment were automated microscopes at third optical inspection (third op). This equipment offered automatic inspection and transfer of bonded lead frames from magazine to magazine. Third optical inspection detected mechanical defects that may have been created during die attach, and wire bonding. Operators looked for pattern changes. The pattern was made up of characteristics such as die bond wetting, wire loop height, and lead frame post points. Any changes in the pattern as the lead frame was fed through the inspection station indicated a defect.

Automated microscopes for second optical inspection (second op) soon followed in the early 80's. Pick and place equipment was the first type of second op equipment. It automatically selected good die from a diced wafer and placed it onto a film carrier or a waffle pack. Second op inspection equipment caught on rapidly because it incrementally increased die bonding equipment throughput. Second optical inspection was performed on individual die that had been sawn and passed wafer sort electrical tests. The die did not have to be removed from the wafer. Die were inspected both for wafer processing defects and for defects generated in the course of sawing and separation from the wafer. Even though individual die passed electrical tests at wafer sort, indicating a good die, certain lingering processing defects may still lead to subsequent failures. Some of the defects generated in die separation will fit this category.

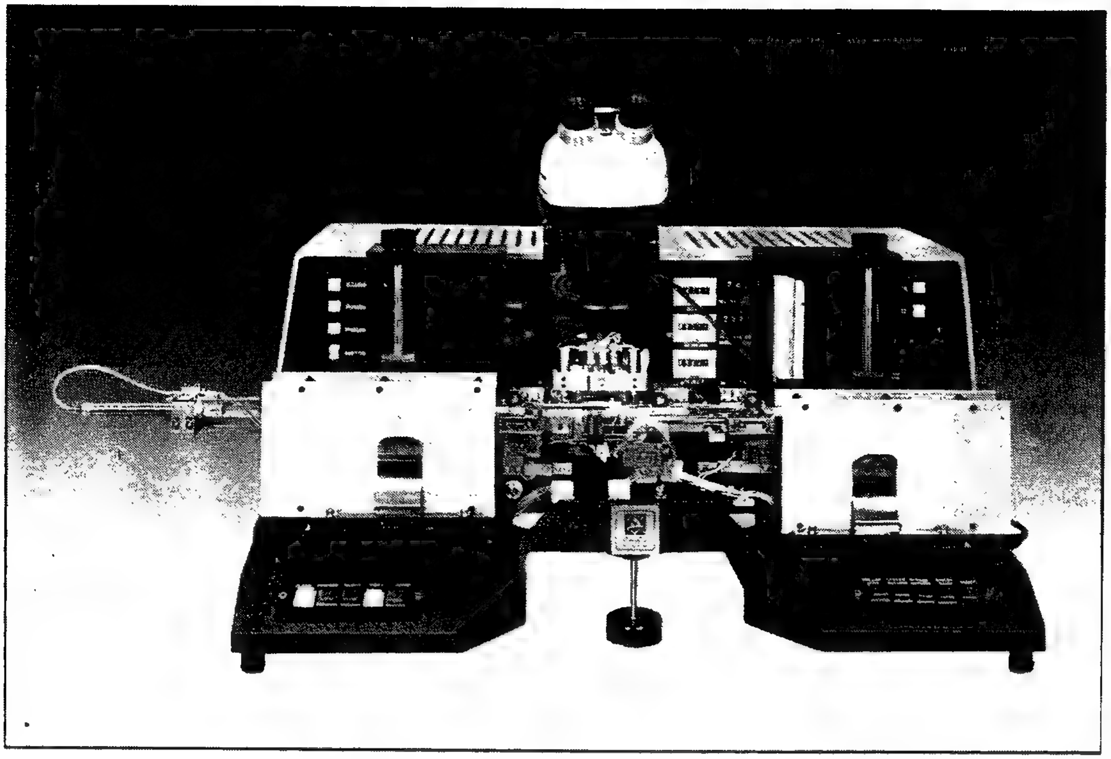
Second optical inspection and third optical inspection machines can be seen in Presentation 5.4.1.1.3-1.

For years, second op had been used to determine if a die still had four corners and was not chipped or cracked and third op was used to sort out improperly wire bonded devices. But, by the late eighties, these functions were incorporated into die bonders through the use of pattern recognition, process control and sensors.

Pattern recognition worked well to a certain degree for detecting chips and cracks, yet the early technology used had a couple of drawbacks. One was that it was too slow in comparison to a human observer. An observer can quickly scan a diced wafer for symmetry between die. When a device is dissimilar, it can be zoomed in on for further examination. Early pattern recognition systems did not have this capability. Early systems checked bit by bit. Moreover, dicing yields were poor. So, this involved substantial computer processing time. Thus, throughput suffered.

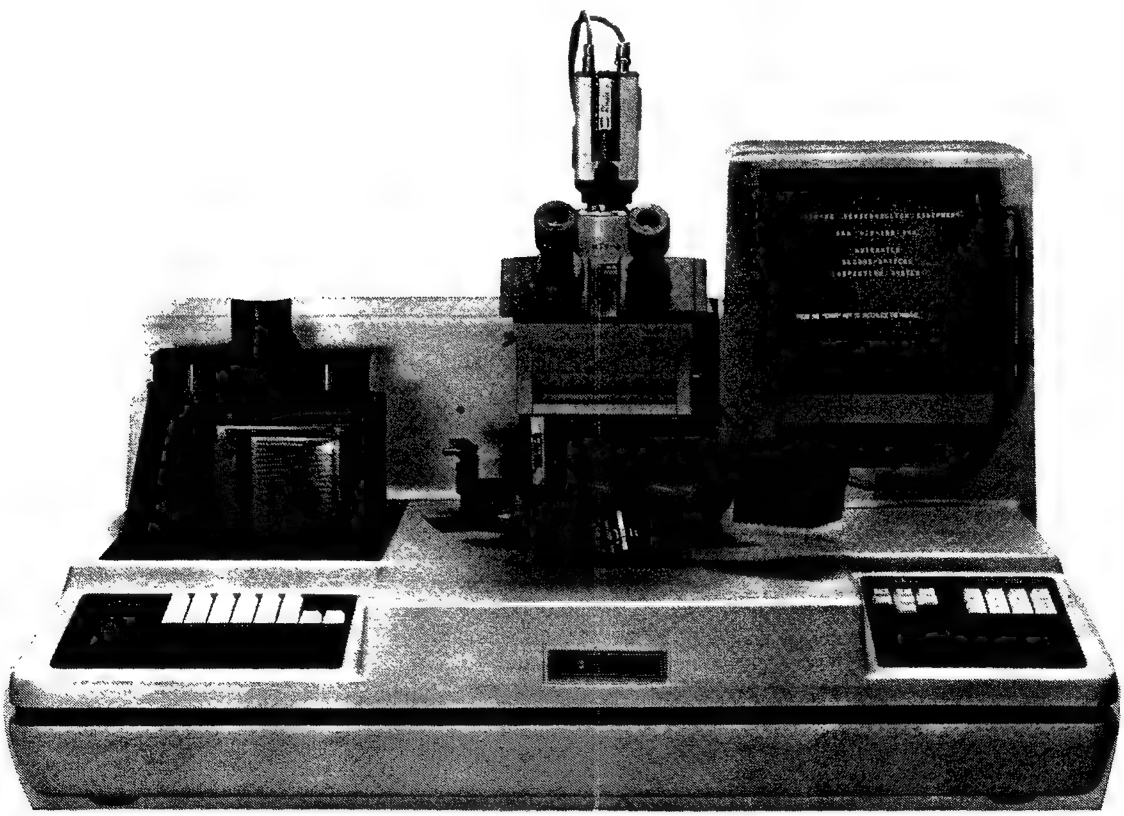
The other limitation of pattern recognition was an inability to resolve beyond gross defects. This problem increases as device sizes decrease. Consequently, systems using human inspectors remained dominant until more sophisticated pattern recognition systems were developed and incorporated into bonding equipment.

Pattern recognition is a good example of how second optical inspection, die bonding and wire bonding have become more sophisticated. Die bonding equipment uses pattern recognition to identify and inspect for good die before they are bonded. Wire



Second Optical Inspection Station

Source: Viking Semiconductor Equipment



PF 335 Third Optical Inspection Station

Source: ASM
2254-22

Presentation 5.4.1.1.3-1

Optical Inspection Stations

bonders do the same, only for wire bond testing. In addition to pattern recognition, systems also became able to evaluate their work, using feedback control capabilities built into the machine. The net effect is that optical inspection started to be carried out in die and wire bonders instead of as a separate function.

5.4.1.2 Technology

- **Self-test and self diagnostics are now critical features in modern bonders.**
- **Wire length, loop height and narrow lead and pad pitch are causing dynamic changes with wire bonding equipment.**
- **Inspection equipment is slowly phasing out as inspection becomes of function of bonders.**

This section contains descriptions of the applications and technologies used by die bonding, wire bonding and assembly inspection equipment.

5.4.1.2.1 Die Bonding Technology

Modern automated die bonders are extremely sophisticated. They are equipped with complex positioning and optical equipment to accomplish die-attach operations. Today's bonders locate a good die, determine positioning for pickup, calculate the exact attachment site, inject the appropriate amount of adhesive on the die substrate, attach the die and provide inspection/identification data. Adhesives used are solder pastes, gold preforms, liquid epoxies and solid organic polymers.

The type of adhesive used dictates the major operative and mechanical differences in die bonders. Consequently, bonding adhesives are an important driver of die bonding equipment technology.

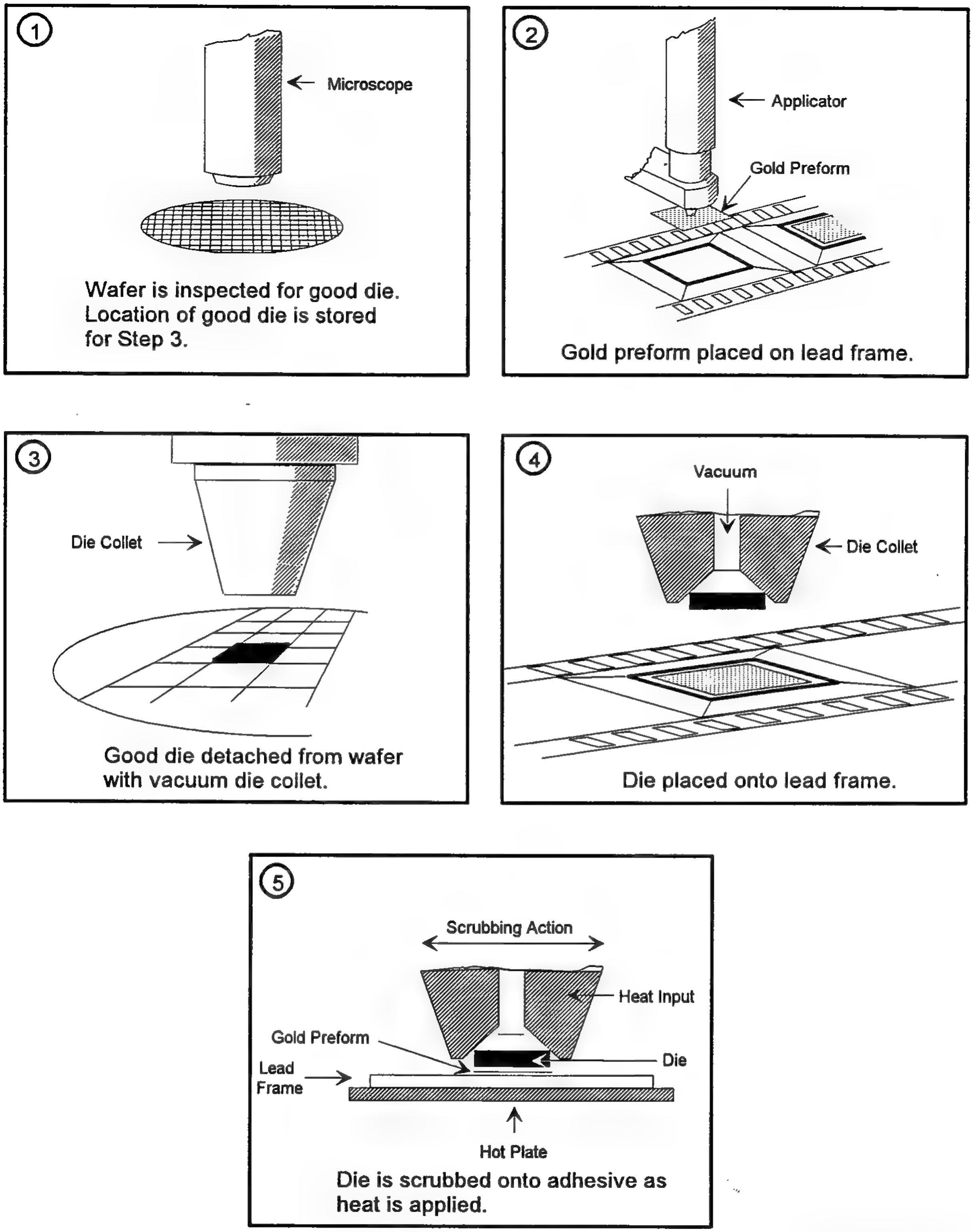
Bonding Adhesives

There are four ways bond die to a lead frame. These use gold eutectic preforms, organic adhesives, solder and silver glass.

Eutectic bonding is the oldest method used. It offers the best conductivity between lead frame and die. In this method, a foil preform made of gold and silicon is placed onto the lead frame. Then, the die, lead frame and preform are heated to about 400 °C. At this temperature, the preform is in a transition state between solid and liquid. The die is then scrubbed onto the adhesive to fuse die with frame (see Presentation 5.4.1.2.1-1).

Organic adhesives are the most common. There are three types of organic adhesives: Thermosetting epoxies, thermoplastic polymides and silicones. All are simpler to use and less expensive than eutectic bonding. In this method, a drop of liquid adhesive is placed onto the lead frame and the die is then placed over the adhesive (see Presentation 5.4.1.2.1-2). Organic materials offer low process temperatures, low stress, and low cost relative to inorganic materials. However, organic adhesives also contain chemicals that can interact with other materials causing chemical attack of metallization, degradation of wirebonds, and electrical leakage. These all lead to performance or reliability problems.

The third method uses solder to bond die to the frame. This method is almost exclusively associated with transistors. With solder-

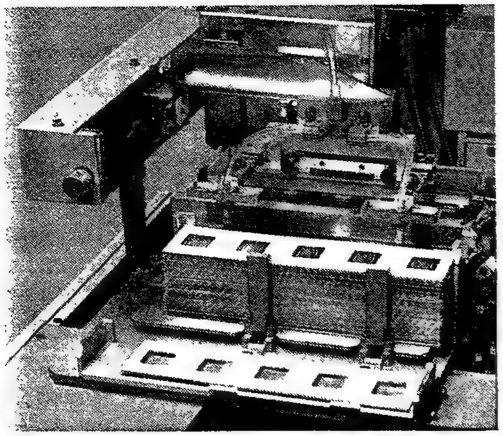


Source: VLSI RESEARCH INC
2254-27D

Presentation 5.4.1.2.1-1

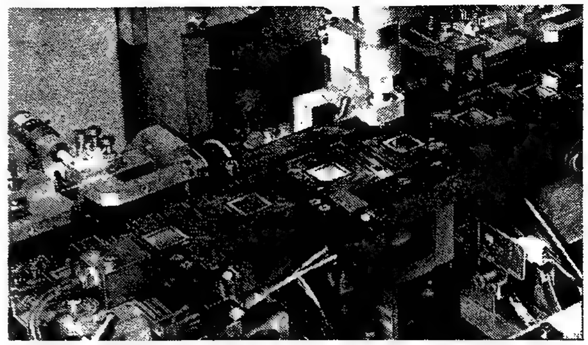
Eutectic Die Bonding Method

① Lead frames are placed on the workholder



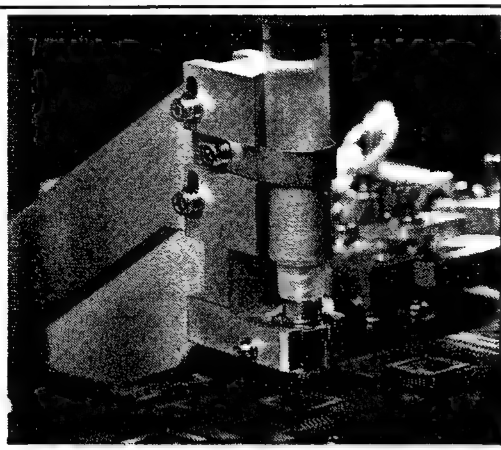
Source: ASM

② Workholder advances lead frame



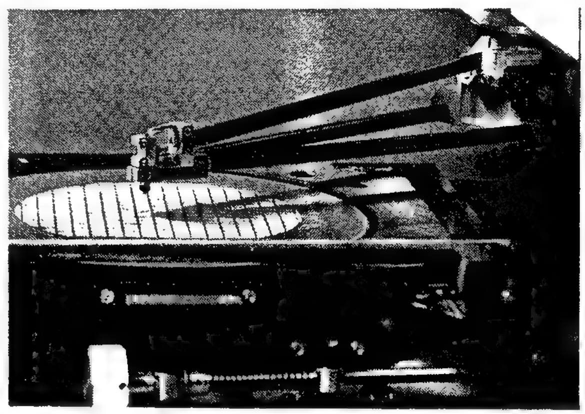
Source: ASM

③ Epoxy is dispensed onto lead frame



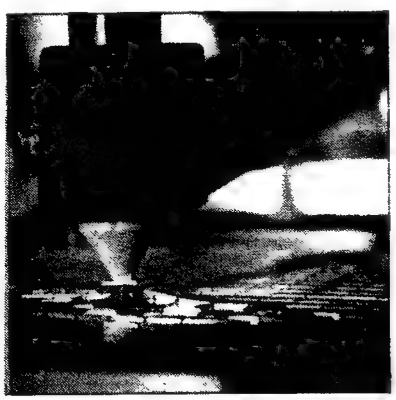
Source: ASM

④a Die is detached from wafer



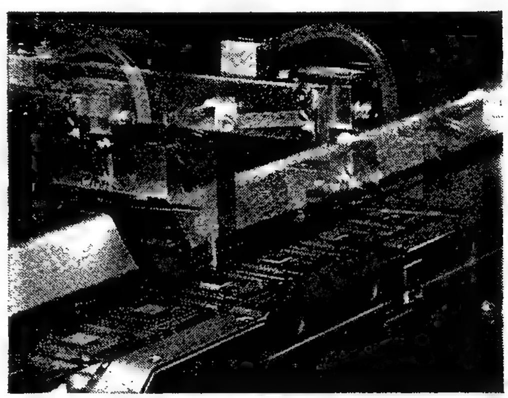
Source: ASM

④b Close up of die detachment



Source: Kulicke & Soffa

⑤ Die placed onto lead frame



Source: ESEC

2254-28

Presentation 5.4.1.2.1-2

Epoxy Die Bonding Method

ing, the lead frame is heated, then a alloy preform is placed on the frame and melted. A die is then bonded on the frame (see Presentation 5.4.1.2.1-3).

Solder has also been used for gang wire bonding techniques. The difference with gang bonding is that die and wire bonding processes are combined into one, attaching pads on the die face to leads simultaneously.

Solder bonding has a number of limitations. It may cause potential die cracking from high temperatures, from mismatched thermal expansion of packages and substrate, as well as potential contamination from fluxes.

The fourth method uses silver filled specialty glass. This method is similar to the epoxy/polymide bonding method, except that the die is placed directly into the package. A measured amount of heated silver glass paste is dispensed onto the package and then the die is placed over the paste (see Presentation 5.4.1.2.1-4). Silver glass has gained popularity for large devices. Silver glass bonding is electrically similar to eutectic bonding and it offers a closer match in thermal coefficient of expansions between the die bonding material, and lead frame. However, it may cause potential die cracking from high temperatures, from mismatched thermal expansion of packages and substrate.

Industry practices regarding die attach adhesives continue to evolve. In the mid-eighties, only 10% of commercial products still used eutectic methods. The trend away from eutectic bonding has leveled off and there is a new trend from polymides back to epoxies.

Eutectic continues to offer technical benefits over less expensive alternatives, though the benefits do not outweigh the costs. Most users of eutectic technology stay with it because of military standards.

The movement away from eutectic first benefitted epoxies. Then as industry's concern with contamination grew, polymides came to be preferred over epoxies. Today's low-contamination epoxies are being used more frequently than polymides. Silicones have not proved successfully. Nevertheless, from an equipment perspective, the consequence of epoxy use over polymides is minimal since both adhesives are dispensed in a similar manner.

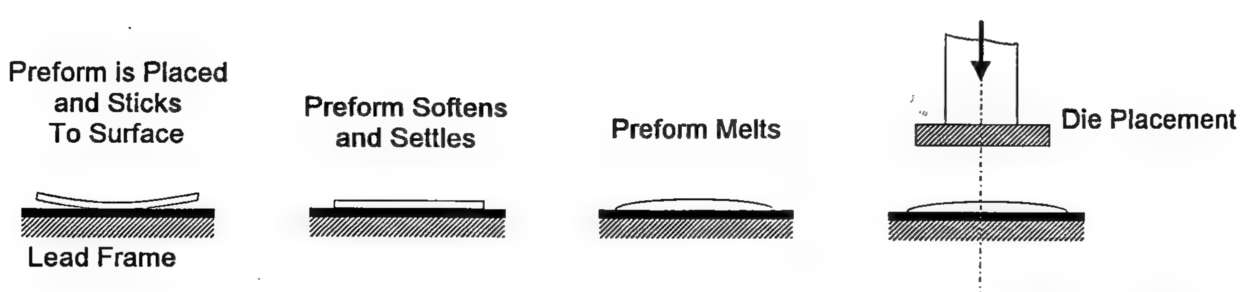
Technological Demands

The die bonding industry has been driven by the need to reduce adhesive wastage in fillets†, eliminate voids under the die and improve XYZ positioning. In response to

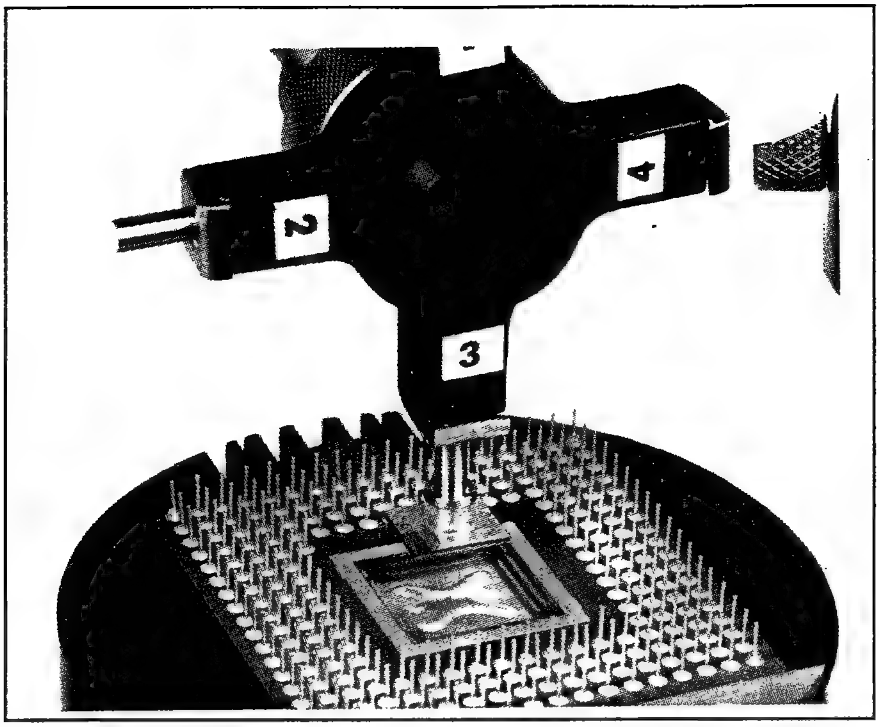
† Fillets are formed as excess adhesive is squeezed out from under die and onto its side.

Presentation 5.4.1.2.1-3

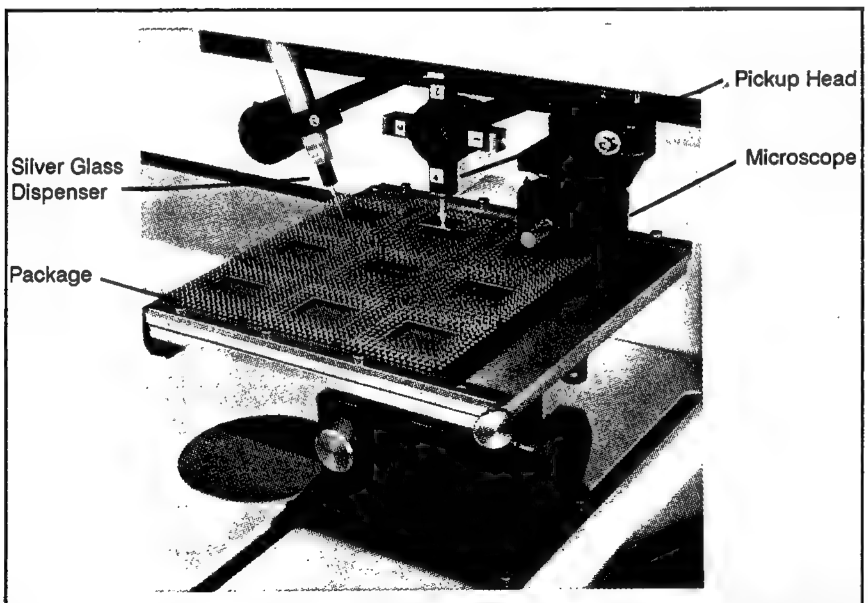
Solder Die Attach Method



Source: Alphasem
2254-29D



Enlargment of silver glass paste application in package prior to die attachment.



Source: Kulicke & Soffa
2254-30

A silver glass bonder work area.

Presentation 5.4.1.2.1-4

Silver Glass Bonding

these problems, some Japanese companies developed an adhesive stamping technology. This method works much like rubber stamping: It uniformly stamps a predetermined quantity of adhesive directly onto the lead frame. According to some sources, such stamping has virtually eliminated fillets. A variation of the stamping method is to inject predetermined quantities of adhesive on the lead frame and stamp it, thereby eliminating fillets.

Another concept is to use multiple nozzle tubes. This method provides void free bonds for die as large as 20 mm^2.

In the mid-eighties, Stauffer Chemical Company developed a film adhesive, which uses a double-sided adhesive tape for attaching die to lead frames. The film adhesive actually replaces the netto film. It is a thin layer of adhesive that rests on a mylar film. It is placed in a film carrier and the wafer is applied to it. The wafer is sawn and then die bonded with no other adhesive.

The concept of a film adhesive has had tremendous appeal to the industry. The idea is simple and intuitively obvious to manufacturing personnel. Hence, it is viewed as a natural evolution as well as an improvement of the current die attach methods being used.

The main advantage of the film system is that it eliminates messy adhesive-dispensing processes. Film technology is also attractive because it combines two steps into one. It also eliminates edge shorting by eliminating the fillet. The principal disadvantage of the film is that it does not permit a delay between dicing and die attach.

Moreover, film technology runs counter to two current practices. One such practice is the partial saw-through of the wafer. The principal advantage of partial saw-through is that the dice on the wafer are held intact until pick and place. They are separated by breaking just before pick and place. From the film technology point of view, partial saw-through is unacceptable since the film must be cut completely through if a clean break in the film is to be obtained. Consequently, this has limited its acceptance.

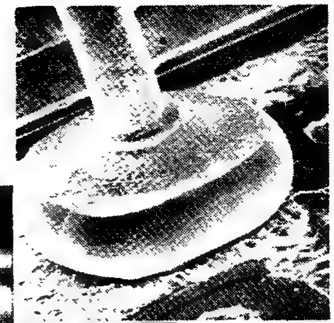
Another technological transition taking place is automatic inspection in die bonding equipment. Die bonders have high throughputs, so large amounts of good product can be wasted in a short time if a die bonder should fail. Self-test and self-diagnostics are now incorporated into the latest die bonders as a result. Self-test methods allow the die bonder to 'stop-on-fail'. Self-diagnostics pin-point the problem so that equipment can be quickly brought up after a failure. This minimizes lost production time from a failure. In addition, interfacing probers and die bonding equipment to obtain wafer maps is implemented in modern bonders.

5.4.1.2.2 Wire Bonding Technology

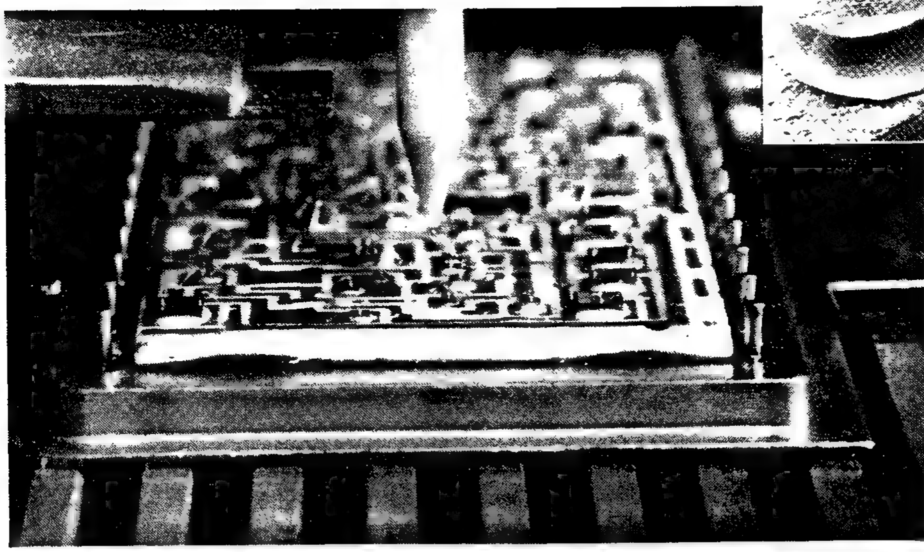
Wire bonding is a critical step in semiconductor device production. Typically 90% of an IC's cost has been invested by the time it reaches a wire bonding stage. The loss is significant if the IC has to be scrapped because of a defective bond. Therefore, the electrical connections between the contact pads of a die and the leads on its package must be perfect.

Several techniques have been developed for connecting bonding wire between device pads and package leads.

The two most common methods are ball and wedge (see Presentation 5.4.1.2.2-1). For ball bonding, a precisely sized ball, usually made of gold, is formed on the end of a wire by melting a measured amount of wire with heat. The ball end of the wire is

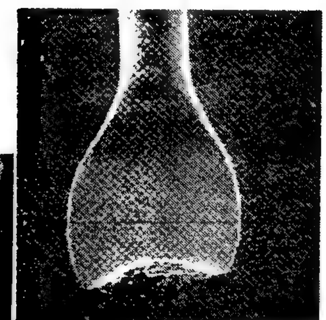


Ball Bond

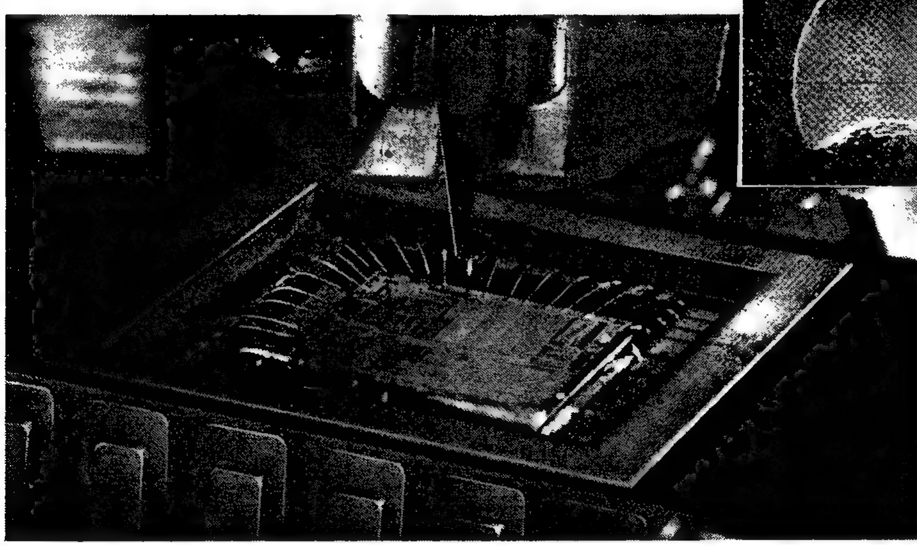


Source: Kulicke and Soffa

Gold Ball Bonder



Wedge Bond



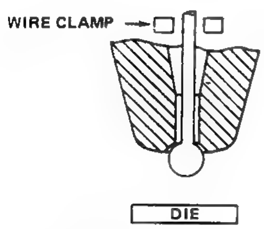
Source: Kulicke and Soffa
2254-17

Wedge Bonder

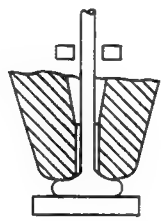
Presentation 5.4.1.2.2-1

Wire Bonding Methods

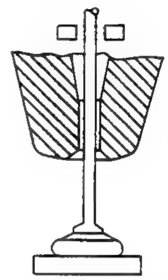
then thermosonically welded to an aluminum pad on the die using heat and ultrasonic energy. Then, an ultra-fine wire is carefully threaded out through a tiny hole in the bonding tool which is about the size of a pencil lead. The wire bonder moves the tool along a carefully controlled path to form a loop between the die and package. Here a wedge bond is formed. Finally, the wire is wedge bonded to the lead frame and broken off after the weld, and the cycle begins again. Presentation 5.4.1.2.2-2 demonstrates the ball and wedge bonding method. All ball bonders use a wedge bond to bond wires to lead frames. Wedge bonders use a wedge to bond on the pads and leads. This method is shown in Presentation 5.4.1-.2.2-3. Wedge bonding is typically used in ceramic packages and hybrids.



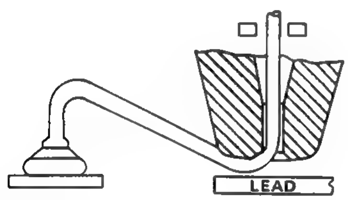
The capillary is targeted on the die's bond pad and positioned above the die with ball formed on the end of the wire and pressed against the face of the capillary.



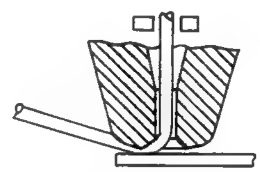
The capillary descends, bringing the ball in contact with the die. The inside cone, or radius, grips the ball in forming the bond. In a thermosonic system, ultrasonic vibration is then applied.



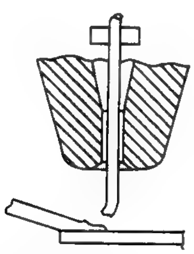
After the ball is bonded to the die, the capillary raises to the loop height position. The clamps are open and wire is free to feed out the end of the capillary.



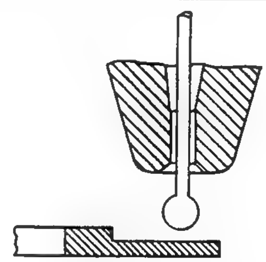
The lead of the device is positioned under the capillary which is then lowered to the lead. Wire is fed out the end of the capillary, forming a loop.



The capillary deforms the wire against the lead, producing a wedge-shaped bond which has a gradual transition into the wire. In a thermosonic machine, ultrasonic vibration is then applied.



The capillary raises off the lead, leaving the stitch bond. At a pre-set height, the clamps are closed while the capillary is still rising with the bonding head. This prevents the wire from feeding out the capillary and pulls at the bond. The wire will break at the thinnest cross-section of the bond.



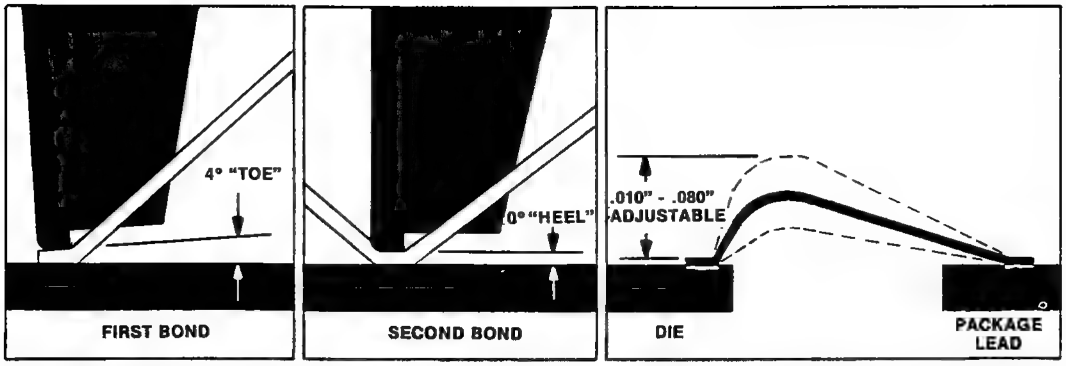
A new ball is formed on the tail of wire which extends from the end of the capillary. A hydrogen flame or an electronic spark may be used to form the ball. The cycle is completed and ready for the next ball bond.

Source: Kulicke and Soffa

2254-36

Presentation 5.4.1.2.2- 2

Ball and Wedge Bonding Cycle



Unique toe-and-heel tool motion. First bond is made with the tool at a 4° angle. Assures a stronger bond and minimizes risk of deforming the wire at the heel. Second bond is made with the tool flat. Sharp heel nicks wire for easy breaking after bond.

Looping height adjustable. Operator can set wire loop to precise height between .010" and .080". Height remains constant for all bonds until reset.

Source: Kulicke & Soffa
2254-18

Presentation 5.4.1.2.2-3

Wedge Bonding Techniques

In bonding wires to die and package, 'thermocompression' bonding, 'thermosonic', and 'ultrasonic' bonding techniques are applied. Thermosonic and ultrasonic are the most common methods used today. Ball bonders use thermosonic bonding techniques. Wedge bonders use ultrasonic bonding techniques.

Thermocompression bonding was the first method used. It requires an accurate and precisely controlled combination of heat and force. With this method, the device to be bonded is heated up to 300 to 350°C. Force is then applied between the range of 40 and 50 grams for the (first) ball bond and between 70 and 90 grams for the (second) wedge bond. Thermocompression is seldom used today. It has largely been replaced with thermosonic.

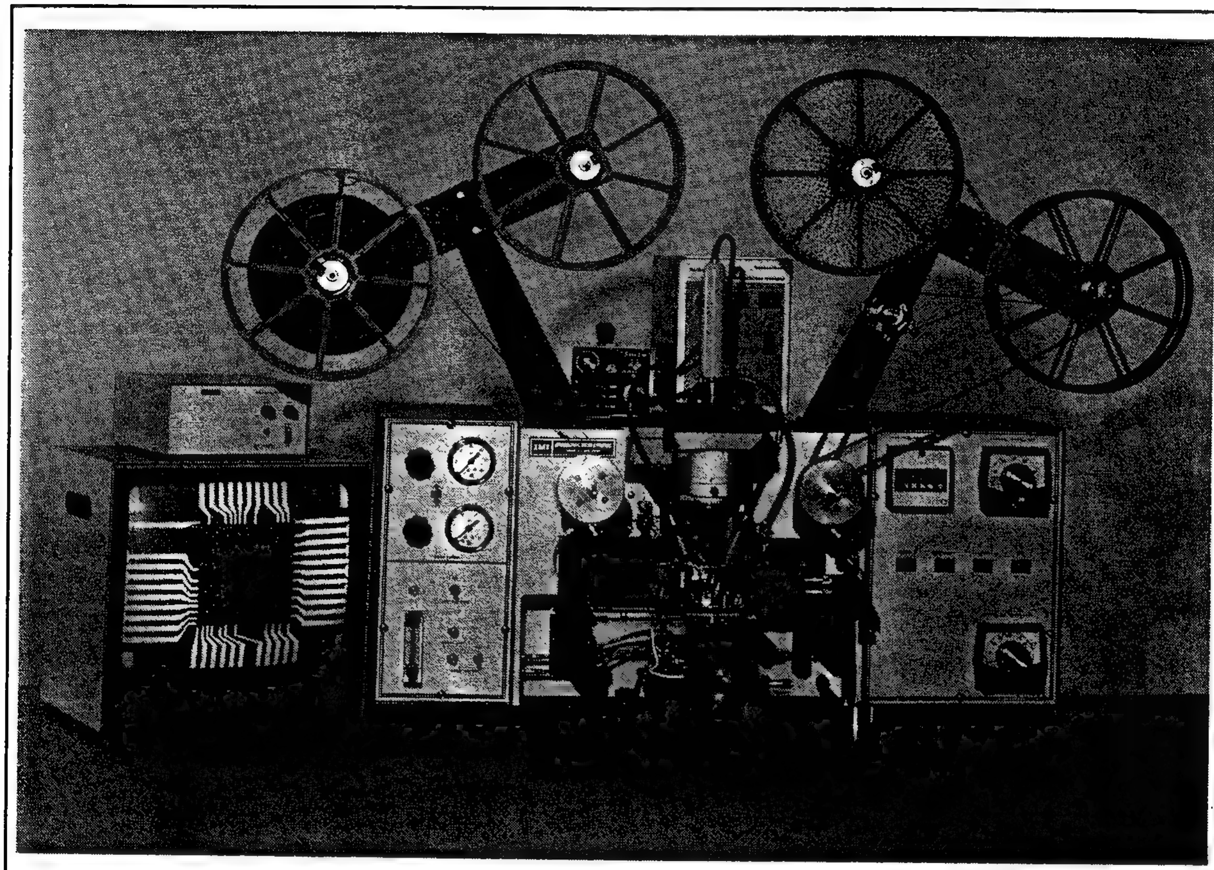
Similar to thermocompression, thermosonic ball bonding utilizes heat and force, but to a lesser degree. What makes thermosonic bonding unique to thermocompression bonding, is its use of ultrasonic vibration. With thermosonic bonding, typical bonding temperatures are in a range of 100 to 150°C. Many devices can be bonded at room temperature. Lower bond forces are also used. Typical forces used are 30 to 40 grams for a ball bond. Generally, higher temperatures require lower bond forces.

Ultrasonic wedge bonding only uses ultrasonic energy, i.e. mechanical vibrations above 20,000 vibrations per second, and force. No heat is applied. The weld is done at room temperature and require forces of 60 to 70 grams. Aluminum wires are generally used in ultrasonic bonders.

Gang bonding systems bond all leads simultaneously. Gang bonding can be broken up into two essential segments, TAB and flip chip. TAB uses etched tape to make the chip-to-lead interconnect. Instead of using wire on a spool, the wiring is etched from a thin film. This film is then sandwiched in a mylar film. TAB bonding involves the application of extreme pressure and heat onto the die in order to bond all tape leads to the device simultaneously. Another TAB technique, single point bonding (SPTAB) is more similar to conventional wire bonding. Like wedge bonding, it uses small tools to ultrasonically bond each lead separately. SPTAB produces higher yields and more

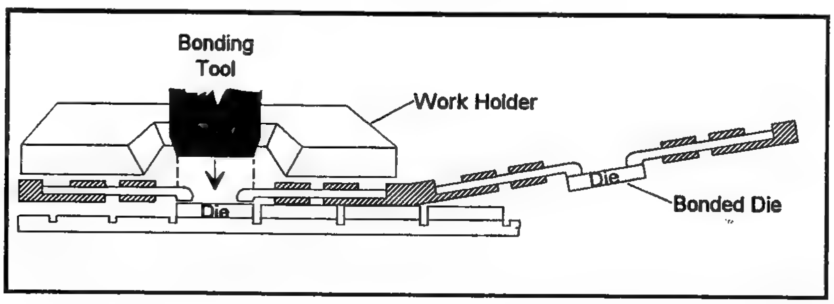
reliable bonds than gang bonded TAB. It is also more flexible and therefore more suited to the lower production volumes of high lead count devices.

Gang bonded TAB has two subsegments, inner lead bonders and outer lead bonders. Both are needed to make a TAB bond. In the TAB bonding process, an etched copper beam tape is rolled up in reel form. Reels are then loaded on an inner-lead bonder. The bonding tool presses the copper leads of the beam tape to the 'bonding' pads of the IC die, simultaneously bonding all leads (see Presentation 5.4.1.2.2-4). The oldest TAB methods use gold bumps that are



Source: International Micro Industries

Inner Lead Bonder



Source: VLSI RESEARCH INC
2254-19D

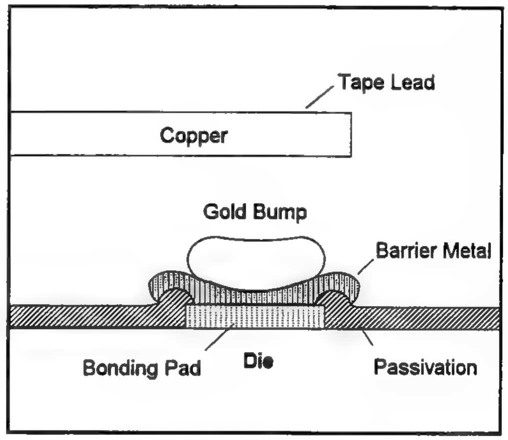
Presentation 5.4.1.2.2-4

Illustration of Inner Lead Bonding

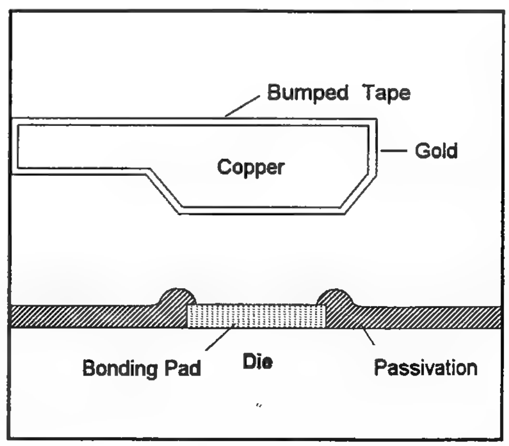
lithographically etched on the bonding pads. Today these bumps are formed into mesas. Newer methods applies bumps directly to the end of the tape (see Presentation 5.4.1.-2.2-5). The bonding tool is then raised and a new tape frame and chip are placed into proper position for a repeat bonding operation. The tape and bonded dice are then coiled on an output reel. This can then be outer lead bonded to a lead frame or even sent to the user who spider bonds the outer leads directly to a substrate (see Presentation 5.4.1.2.2-6). This process is called outer lead bonding. Presentation 5.4.1.2.2-7 shows examples of tape automated bonded chips.

The most recent development in TAB is laser tape automated bonding. Laser TAB was developed by the Microelectronics and Computer Technology Corp. This process promises the speeds of gang bonding with better reliability than wire bonding. It virtually eliminates mechanical stress, and thermal stress. Laser TAB requires no physical contact with the lead. It can also be accomplished at room temperature. The laser TAB process focus is a beam over a lead and is pulsed once (see Presentation 5.4.1.2.2-8). The process is then repeated with each subsequent lead until the entire die is bonded. Laser TAB was created with high lead count, small pitch devices in mind. With laser TAB, lead and pad pitch is limited only by the laser beam diameter as compared to the diameter of the tool used by single point bonders. Despite its advantages, Laser TAB has not caught on. This is mainly because as the laser is continually pulsed through the glass, it clouds over in a small period of time. Consequently, results have not been repeatable.

Flip chip is another alternative. With the flip chip process a bare chip is turned upside down and bonded directly to a printed circuit board (PCB) or other substrate (see Presentation 5.4.1.2.2-9). Electrical connection from chip to substrate is achieved through the use of solder bumps on the chip surface. Solder bumps may be placed over virtually the entire IC surface, instead of merely the perimeter. This results in reduced amount of silicon used and higher package density. It is also suitable for multichip hybrids involving thousands of interconnections. By using a flip chip with solder bumps, manufacturers can easily increase pin counts. Also, manufacturers are not constrained by lead pitch, since flip chips do not have any leads. Other advantages of using flip chip packaging are fast throughput times and efficient use of board area (see Presentation 5.4.1.2.2-10). With



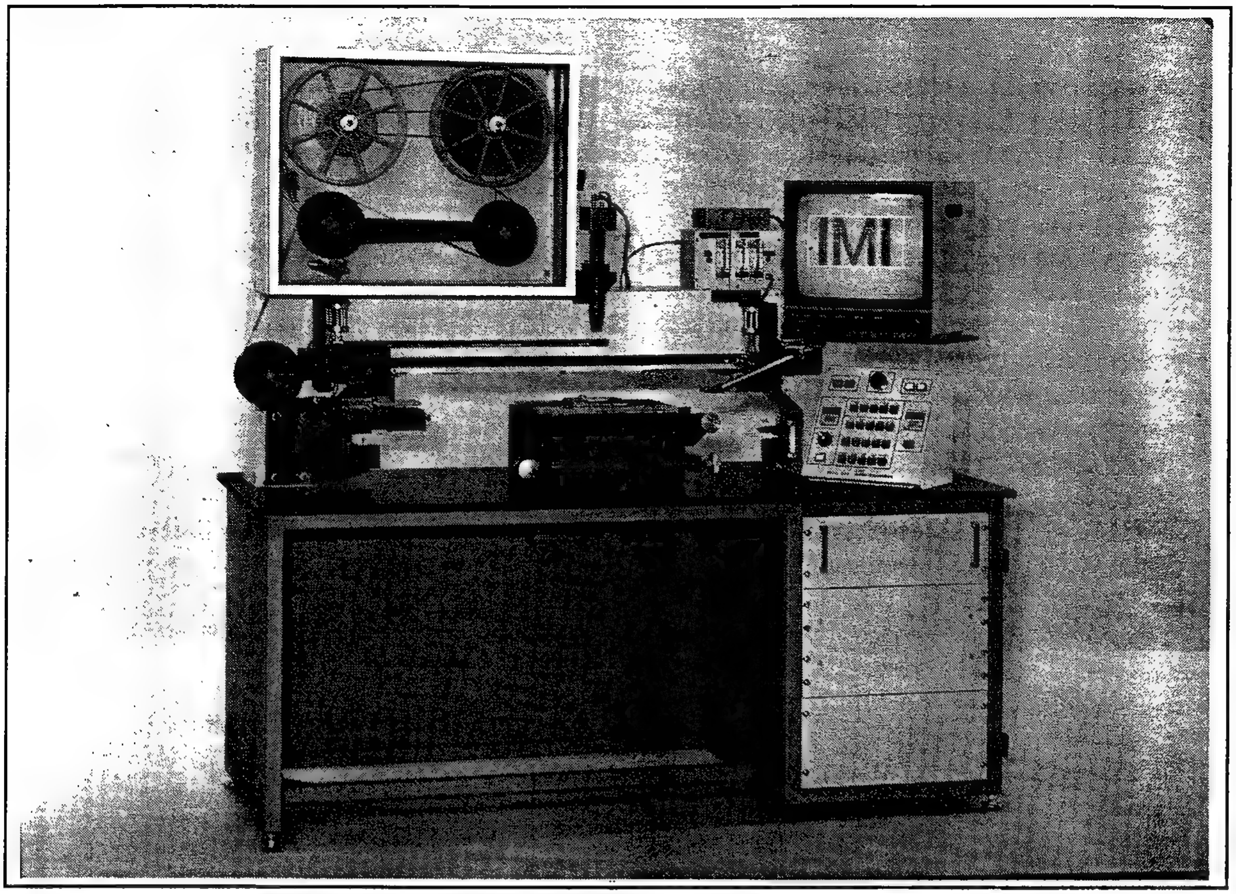
Bumped Bonding Pads



Source: VLSI RESEARCH INC
2254-113D

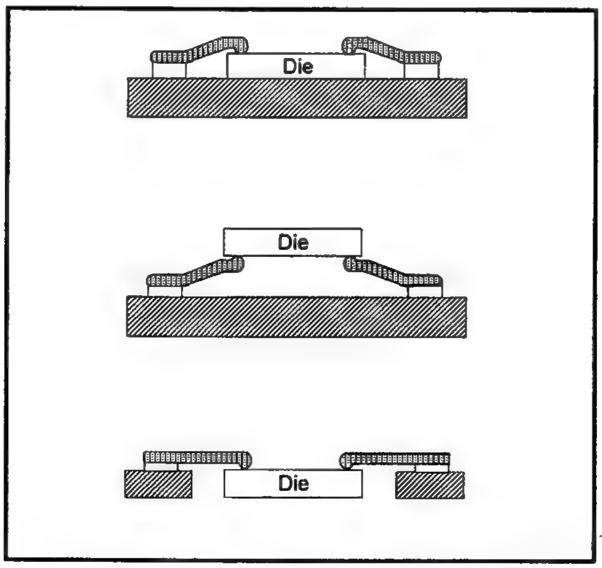
Presentation 5.4.1.2.2-5

Bumped Tape



Source: International Micro Industries

Outer Lead Bonder



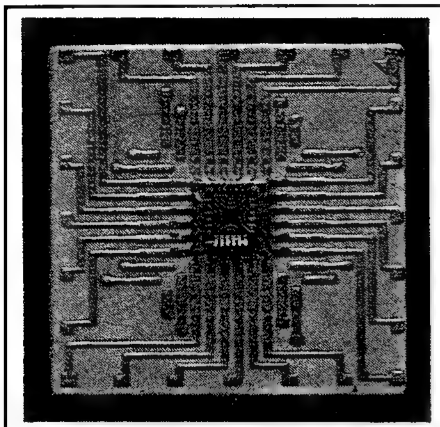
Source: VLSI RESEARCH INC
2254-45D

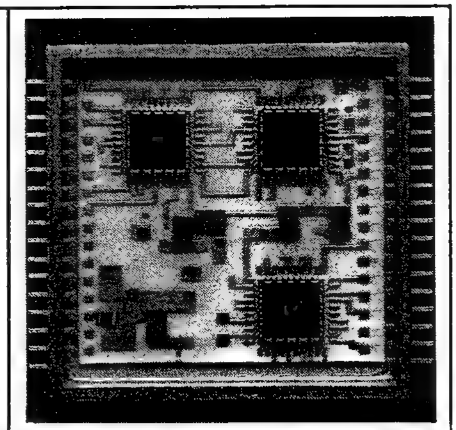
Examples of Outer Lead Bonding

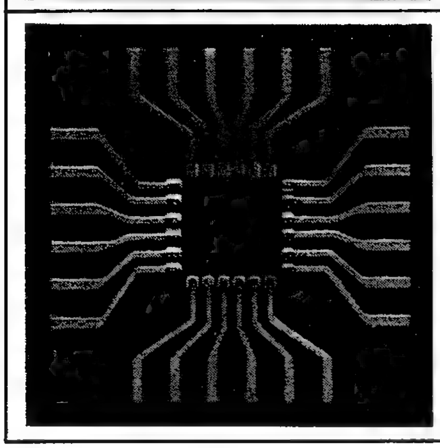
Presentation 5.4.1.2.2-.6

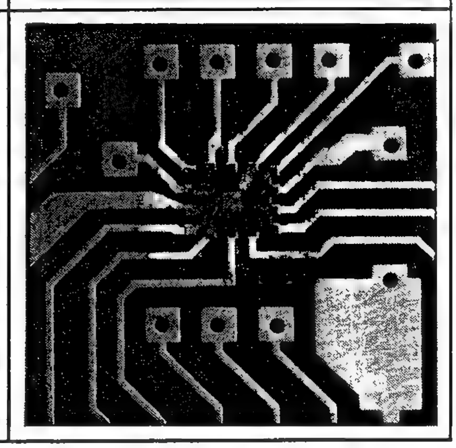
A single chip, multilayer ceramic package with thick film metalization. The test chip was thermocompression, inner lead bonded, excised from the tape carrier, the leads formed and thermocompression bonded to thick film conductors.

A multichip hybrid package with (3) 40 lead chips on multilayer ceramic; other components are wire assembled using hybrid techniques.









A tape mounted IC, inner lead bonded, excised from tape with the leads formed in one tool stroke.

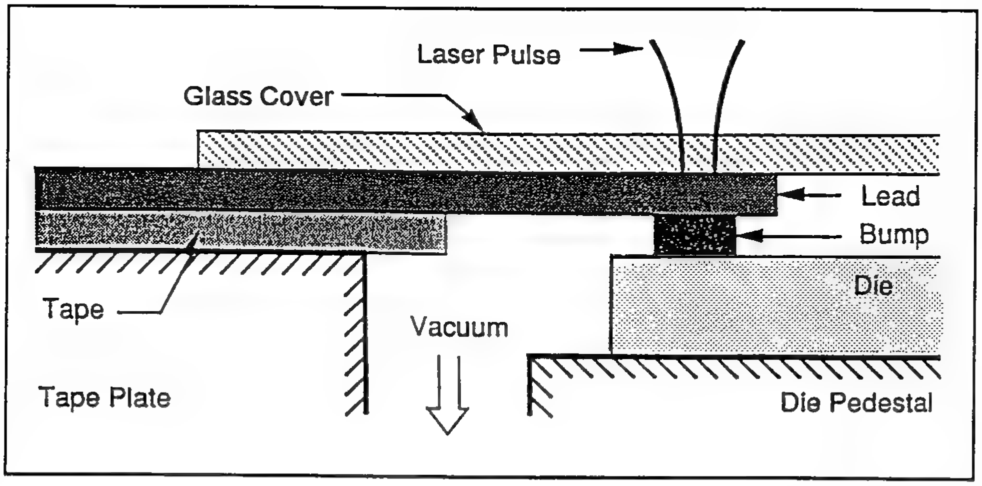
The chip has been thermocompression inner lead bonded, excised from a tape carrier, and face done reflow bonded to the circuit board.

Source: The Jade Corp.

2254-20

Presentation 5.4.1.2.2- 7

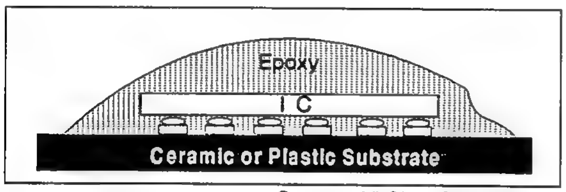
Examples of Tape Automated Bonding



Source: ESI/MCC
2254-43

Presentation 5.4.1.2.2-8

Laser Bonder



Source: VLSI RESEARCH INC
2254-39D

Presentation 5.4.1.2.2-9

Flip Chip Interconnection

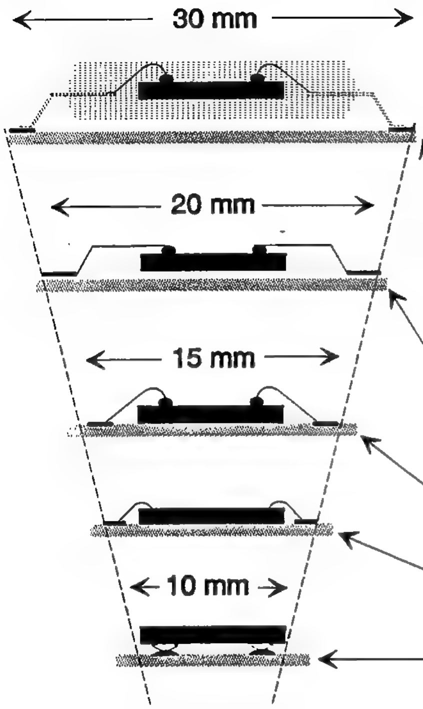
the flip chip interconnection, the short distance between chip and board produces minimal transmission delay and losses at high frequencies, thus producing better electrical performance. Disadvantages with the flip chip solder bump process is the substantial capital investment required and limited availability of bumped ICs. Other disadvantages include an inability to visually inspect the assembled chip; limited availability of bumped chips; difficult flux removal; and thermal transfer complications.

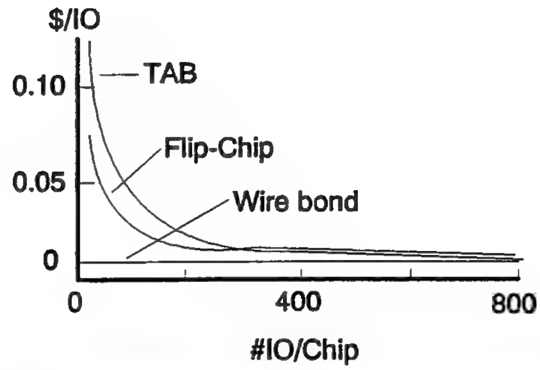
Technological Challenges

The increasing demand for memory in smaller and thinner packages and the requirements imposed by high lead count, increasing die values, and high density semiconductor devices create challenges in wire bonding equipment. These challenges translate into several technological requirements in the design of wire bonders. One requirement is they must have greater bond placement accuracy. This is crucial to ensure that thin bonding wires allow closer placement. Another challenge is wire bonders must permit fine pitch bonding. They must be able to locate and bond smaller bond pads and narrower outer leads caused by high lead counts. In addition, no sagging should occur over longer loop lengths due to increased lead count. Also, bonders must be able to bond and quickly convert to different types of die. These challenges are obsoleting wire bonders built before 1990.

Presentation 5.4.1.2.2-10

Board Usage Drives Interconnection Technology





Bonding Method	Area (mm^2)	% Area Used
Reflow Soldering	900 (100%)	11
Tape Automated	400 (44%)	25
Ball & Wire	225 (25%)	44
Ribbon	160 (20%)	62
Flip-Chip	100 (11%)	100

Source: Texas Instruments

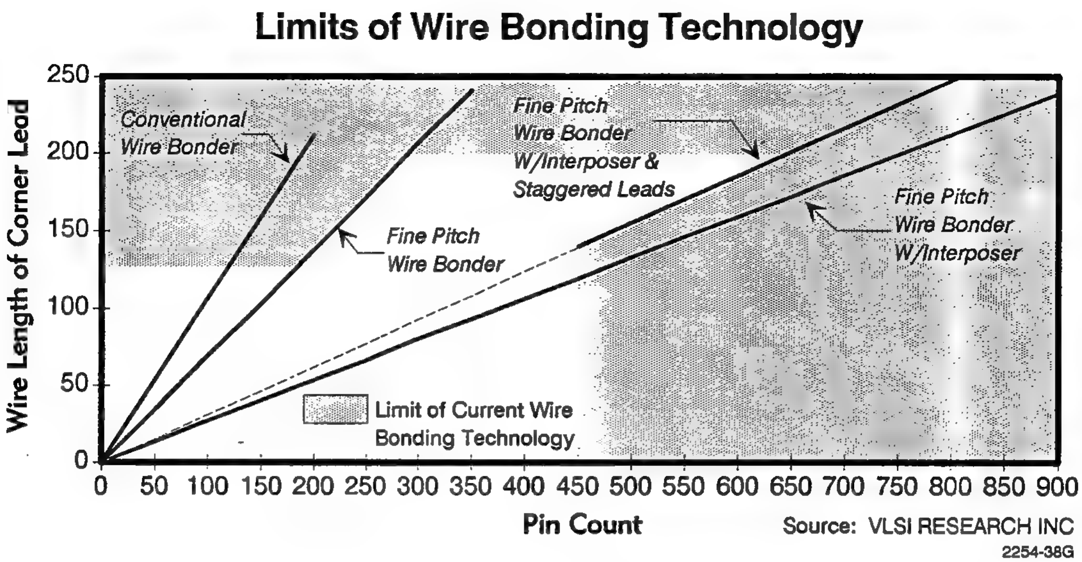
2254-05D

High lead counts are a key driver of wire bonder technology. Lead counts above 130 pads obsolete most wire bonders; those above 200 leads obsolete all but one or two systems (see Presentation 5.4.1.2.2-11). The typical lead count for ball bonding is between 80 and 120, and for wedge bonding is between 120 to 400 leads. High lead count die are typically very big. They can be as large as 680 mils. High lead-count devices need fine pitched pad spacing to place all of the pads on the die periphery. Designers want to use all available silicon, so they often squeeze pad sizes and stagger them in order to pack more active devices on the wafer (see Presentation 5.4.1.2.2-12).

Designers have also tightened up pad pitchs from 6 to 4.0 mils. Current ball bonders reach pad pitches as small as 4.0 mils. Wedge bonders can reach 3.0 mils. In the next five years, pad pitch widths are likely to shrink to 3.5 mils for gold ball bonds and 2.3 mils with wedge bonds, and 3.0 mils for TAB. Consequently, pad pitch is not a significant limitation for wire bonding.

Wire lengths are another issue created for wire bonding by high lead count devices. The difference between the inside lead pitch on lead frames, typically 25 mils, and the pad pitch, affects the wire length needed to span the distance between the lead and the

Presentation 5.4.1.2.2-11

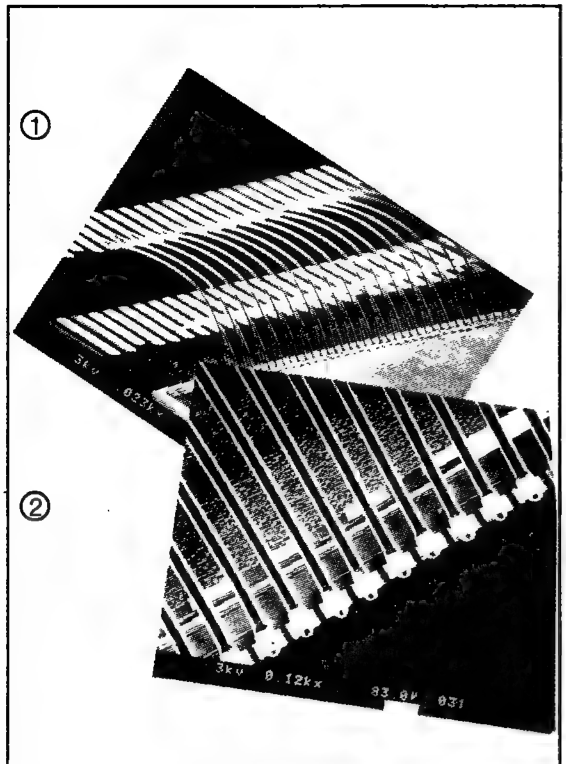


pad. This problem is worse at the corners of the die and lead frame where the wire length must be longest. Long wire lengths are difficult to control due to the slenderness and the looping of the wire. If wire length is too long, wires will be swept over and shorted against each other during injection molding. So, the bonders must have greater control over the shape of the wire loops.

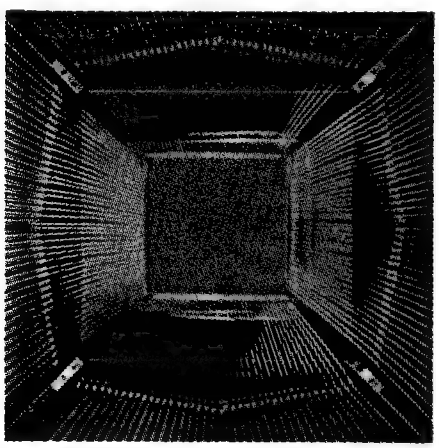
Designers need longer wire lengths to avoid increasing die size for the sole reason of fitting it in the package. Conventional wire bonders are limited to a wire length design rule of 125 mils at the corner lead. Fine pitch wire bonders have far superior control over loop height, variation, and placement accuracy which helps to avoid wire sweep problems at molding. The latest wire bonders can handle a 250 mil wire length which extends their capability to about 200 leads. This can be further extended to 450 leads if a tape interposer is used or 650 leads if both staggered leads and an interposer is used (refer back to Presentation 5.4.1.2.2-11). The interposer is a TAB tape extension that is attached to the lead frame between the leads and the die. The finer lead pitch of the tape places leads closer to the die so that they can then be wire bonded.

With packages becoming thinner, wire loops must also be lower to avoid sticking out of the package. For example, TSOP package thicknesses range between 1.27 mm and 9.0 mm. A 1.0 mm package can have loop heights of no higher than 0.15 mm (see Presentation 5.4.1.2.2-13). 'Super Thin' SOPs (STSOP) with thicknesses between 0.9 mm and 0.5 mm require loop heights that are flat. Hence, TAB is the only solution for these packages. STSOPs are so small, that the die becomes an integral part of the package structure, providing rigidness.

High lead count devices, in addition to STSOPs will be critical drivers of TAB as it continues to gain momentum. These applications will use both wire bonding with tape interposer's and single point TAB. Both are essentially wire bonding techniques. The primary advantage of the interposer over TAB is that one standard tape can be used for each lead frame. This takes advantage of conventional wire bonding's ability to adjust for differences in pad location on



1 - Staggered two tier fine pitch device bonded using 1 mil wire to 3 mil pad pitch and 3 mil staggered lead pitch.
2 - Close-up of bonded 3 mil pad pitch die.



160-lead fine-pitch (4.5 mil) test die.

Source: Kulicke & Soffa
2254-64

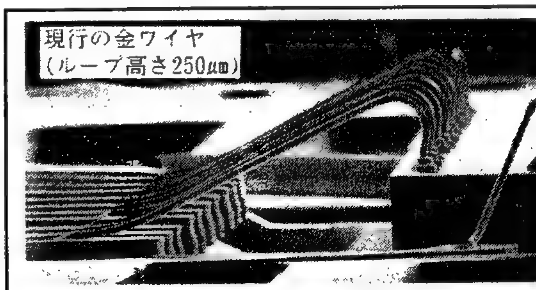
Presentation 5.4.1.2.2-12

An illustration of fine pitch devices.

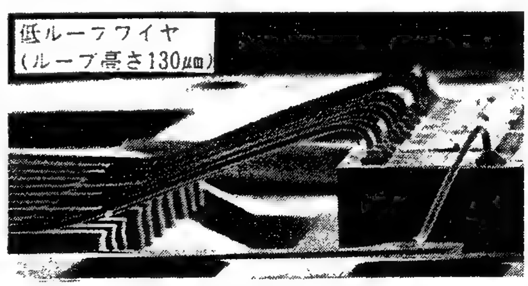
each part number. It also eliminates a lot of tape inventory and the NRE costs of designing custom tape for each design. Single point TAB (SPTAB) tape now offers virtually unlimited lead count potential. SPTAB multilayer tape with lead counts of over 800 is commercially available. Single point TAB has won out over both wire bonding and conventional TAB for pin counts above 200.

Flip chip technologies are also resurfacing as an alternative with the trend toward higher pin counts and finer lead pitch. Flip chip offers the highest lead counts possible.

Device speed is another issue for wire bonding. Cross-talk between wires may be a problem to contend with in the future as pad and lead pitch get narrower and frequencies run faster. When frequencies push



(Loop Height = 250 μ)



(Loop Height = 130 μ)

Source: Semiconductor World, 1991, Vol. 6
2234-40

Presentation 5.4.1.2.2-13

Illustrations of Precise Wire Loops

into the 200+ MHz range, and interconnects become smaller, cross-talk between wires will become a major concern. This is not a problem today. Currently, the fastest microprocessors are running around 50 MHz. However, the frequency rate is expected to double about every three years. One solution to eliminate cross-talk will be to use coaxial wires. This has already been demonstrated using CVD to coat bonding wires with an oxide and a metal.

While TAB is an expensive approach, it offers the best high speed electrical performance for its cost. The latest TAB tape offers a ground-plane layer to reduce noise and cross-talk. This offers substantial advantages for high speed circuit designs. Moreover, it is proven and eliminates the CVD steps needed to make coaxial wires. Nevertheless, these super-high lead count applications will continue to be a small part of TAB equipment demand.

Almost eighty percent of all TAB production is in Japan. There, consumer products are driving demand for low cost Multichip Modules on a single tape. Casio's 50 mm tape line is a good example of this. LCDs are another where TAB is used exclusively. The TAB equipment market in Japan is a custom market that is characterized by close customer-vendor ties. It is dominated by Shinkawa.

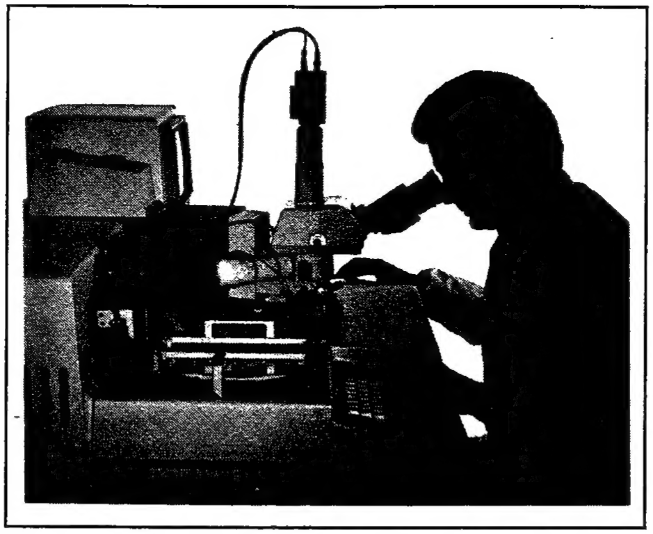
5.4.1.2.3 Assembly Inspection Technology

Inspection equipment is rapidly evolving away. The functions of this equipment are being integrated into die and wire bonders. Wafer mapping from second op equipment is presently found in most die bonders. Also, third op equipment's tasks have integrated into some wire bonders. For example, Kulicke and Soffa now has a wire bond monitor system which detects for broken or missing wires. It also has full SPC capability over critical bonding parameters. As a result, there is very little new technology occurring in assembly inspection, and the equipment found is limited. Presently, second and third optical equipment consists mostly of microscopes and automatic handling systems (Presentation 5.4.1.2.3-1).

Another piece of equipment that is being blended into bonders is die sorting equipment. Die sorters are similar to second op stations. They automatically align the wafer, search the die and sort the good die from the bad die, placing the good die in waffle packs, gel packs and film frames (Presentation 5.4.1.2.3-2). This function is found in many die bonders.

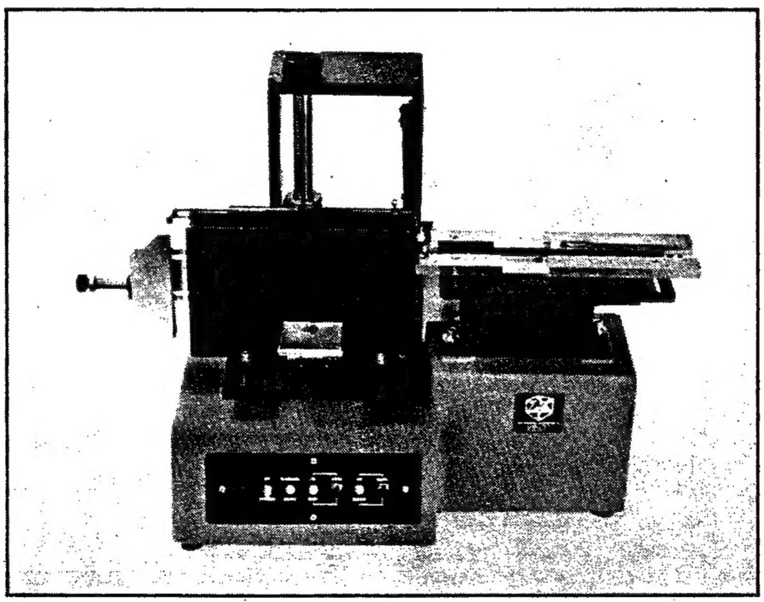
Inspection does continue for some devices. These components are inspected for metal and passivation problems, i.e. lead intrusions or cracks, pinholes, pin-spots, passivation cracks or probe perforations. Metal is one of the most critical layers in processing. These faults can be detected optically. Many metal and passivation faults will pass probe only to be caught at final test, after devices have received environmental test. Environmental tests cannot be performed prior to wafer probe.

MIL-STD 883 is a military standard encompassing test method and procedure for microelectronics. It was developed by the Department of Defense and National Aeronautics and Space administration and is approved for use by all Departments and Agencies of the Department of Defense. The MIL-STD 883 standard was originally formalized and implemented on a wide scale in the late sixties. A major revision was released in 1974 as MIL-STD 883A. A second major revision was made in 1977, becoming MIL-STD 883B. Formalized test methods in MIL-STD 883 include environmental, mechanical, digital and linear electrical test methods as well as various test



Source: Viking Semiconductor Equipment

Metallurgical-quality Microscope

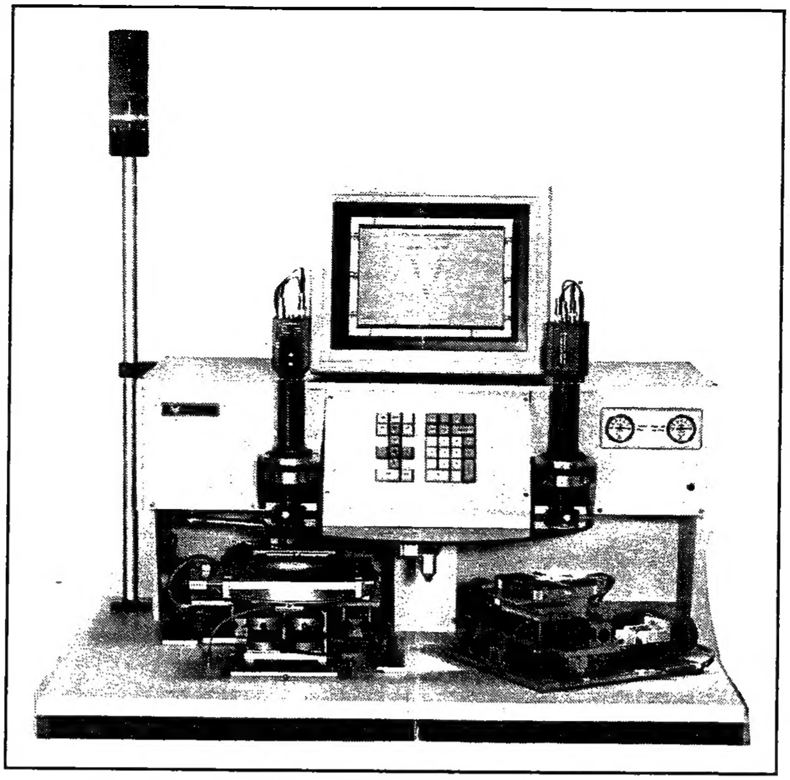


Source: ASM
2254-31

Leadframe On/Off Loader

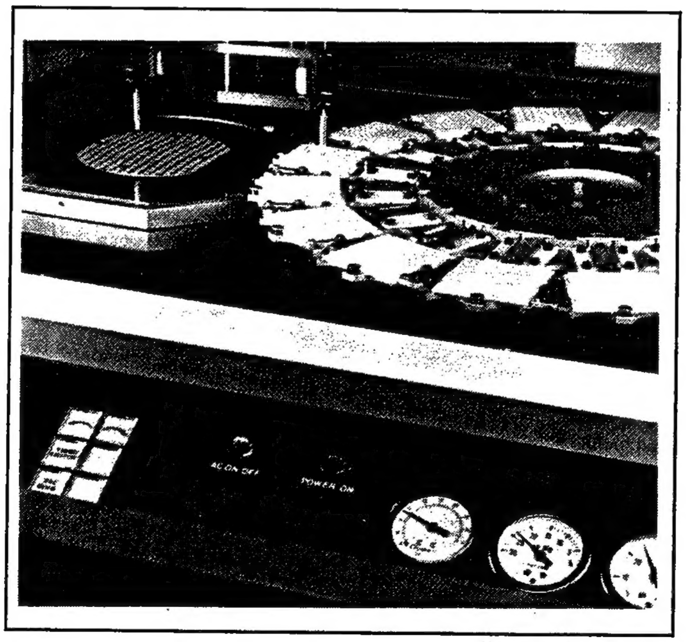
Presentation 5.4.1.2.3-1

Inspection Systems



Source: Viking Semiconductor Equipment

Die Sorter



Source: Laurier Inc.
2254-32

Demonstration of removing good die from the wafer and placing it in a waffle pack.

Presentation 5.4.1.2.3-2

Die Sorting Equipment

procedures. Moreover, it has become a uniform standard for optical and SEM inspection. As a result it has become the de facto standard of the industry.

While a number of test methods may be specified for specific product applications, the most universal in-line visual test methods applicable to assembly are methods 2010.2 Internal Visual and 2009.1 External Visual.

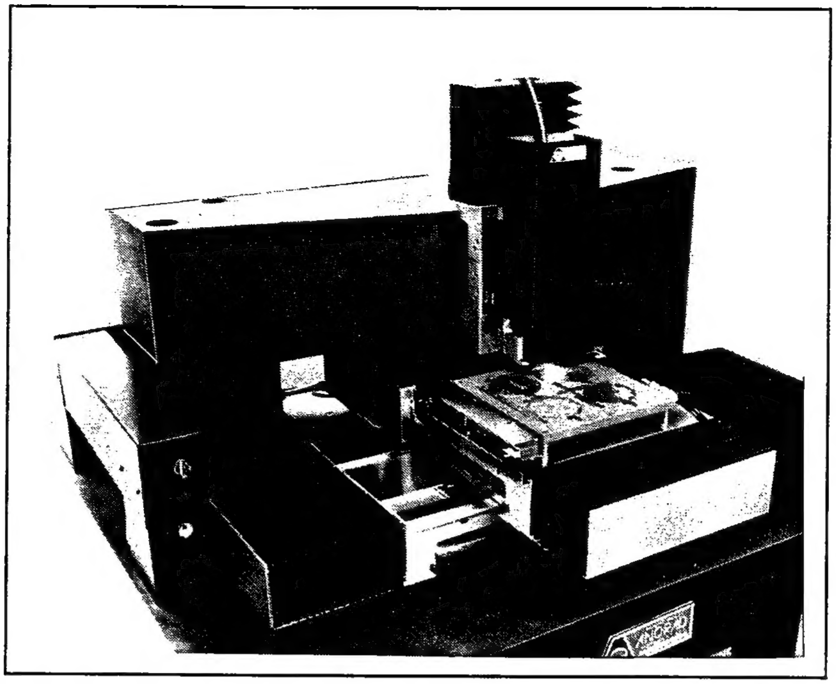
MIL-STD 883 was created to fill a void in inspection standards that existed with integrated circuits in the late sixties and early seventies. These methods and other subsequent ones were developed to detect potential failure mechanisms that might result in wafer processing and assembly, as well as inadequate testing and design margins. The impetus to this standard, beyond the rationale standards per se, was for the improvement of quality and reliability for military and aerospace applications.

Other military standards also exist, particularly for ultra-high reliability deep-space applications. MIL M38510 is one of these. Nevertheless, MIL-STD 883 has survived as the definitive standard for inspections.

Quality is an issue in commercial products by virtue of today's applications. Meantime between Failure (MTBF) is a major concern of OEM's using semiconductor devices. This is true no matter whether the end product is a pacemaker, a television circuit, a process control circuit, or a data processing system. Standardization itself is an equally important factor. Inspection methods, the items inspected, and the inspection criteria are adequately defined and can be understood through such standards.

These factors have also aided in helping MIL-STD 883 become the de facto procedure for all assembly inspections. Commercial grade products will often include some modifications to the standard. One example is the elimination or relaxation of certain accept/reject criteria. Notwithstanding that, if the inspection is performed in assembly, it will usually be per MIL-STD 883 or via some modification of it.

With the increase use of TAB, inspection systems for this bonding method have been developed. TAB inspection systems inspect the height of the bumps on a wafer and the TAB tape inner and outer leads for dimensional conformity (Presentation 5.4.1.2.3-3).



Source: Anorad
2254-33

Presentation 5.4.1.2.3-3

TAB Inspection System